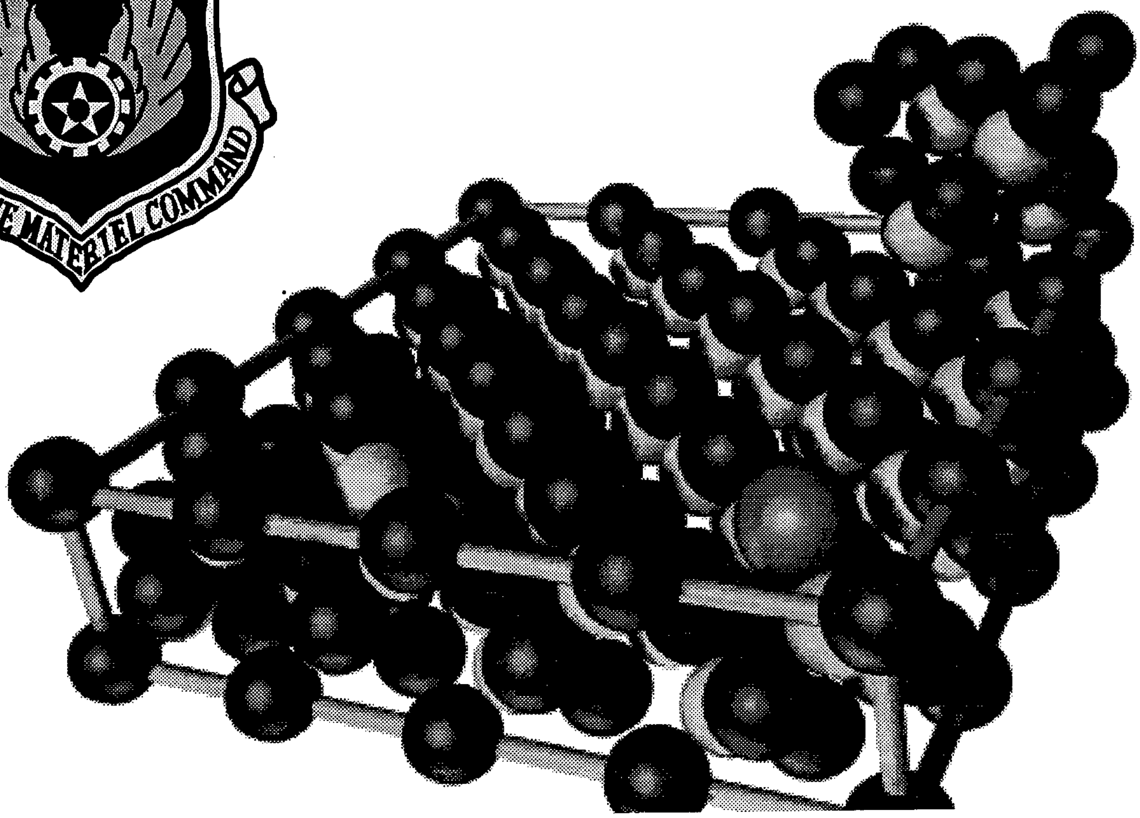
FY98
MATERIALS & PROCESSES
TECHNOLOGY AREA PLAN



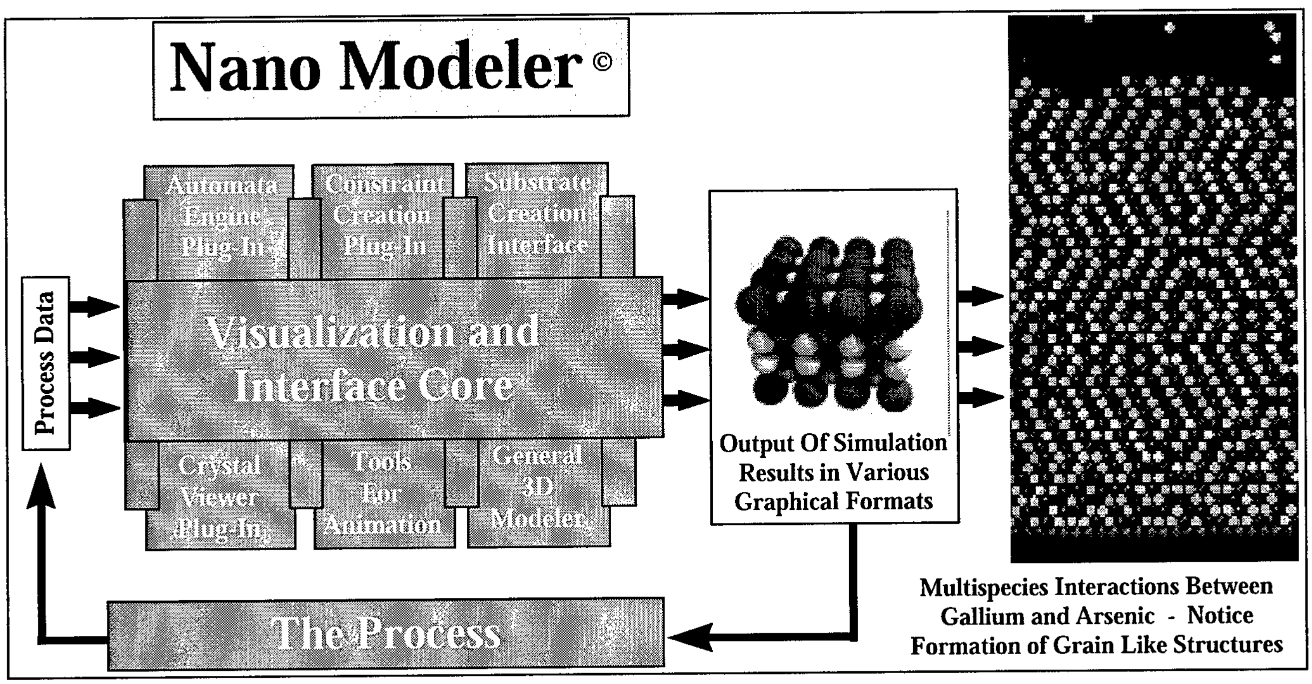
AIR FORCE RESEARCH LABORATORY
WRIGHT-PATTERSON AFB, OHIO

Note: This Materials and Processes Technology Area Plan (M&P TAP) is a planning document for the FY98-03 Science and Technology (S&T) program, and is based upon the President's FY98 Budget Request. It does not reflect the impact of the FY98 Congressional appropriations and FY98-03 budget actions. You should consult WL/MLI, (937) 255–7174, for specific impacts that the FY98 appropriation may have had with regard to the contents of this particular TAP. Additional copies of this document can be obtained via the Internet at "http://stbbs.wpafb.af.mil/STBBS/". More information on the M&P Technology Area can be obtained from the Materials Directorate's web site at "http://www.ml.wpafb.af.mil" where comments can also be made. This document is current as of 1 June 1997.

. . . about the cover

Pictured on the cover is a lattice of Gallium Arsenide from the M&P Technology Area's Nanomodeler©. The Nanomodeler© is a desktop PC software system that models and simulates thin-film materials growth, as illustrated below. The principal focus of the Nanomodeler© is to enable 'interface' design for an array of thin-film materials from electronic devices to thermal barrier coatings. The core Nanomodeler© technology is the combined cellular automata and qualitative modeling methods which allow: (1) materials researchers the opportunity to quickly view several growth simulations saving time, money and intellectual effort; and (2) the opportunity to visualize materials interfaces that are difficult, if not impossible, to model without the use of large parallel processing machines. Other benefits are that the Nanomodeler© is a noncomputer intensive, parametric design system and it provides a key tool for the development of nanoscale materials within this Technology Area. For the M&P Technology Area, the specific definition of "nanotechnology" refers to "nano-scale materials process design".

The overall M&P Technology Area goals for nano-scale materials process design are to (1) strategically position each atom, and (2) make almost any structure consistent with the laws of physics and chemistry. All products are made from atoms, and the properties of those products depend on how those atoms are arranged. If atoms in coal are rearranged, diamonds can be made. If atoms in sand are rearranged (and add a few other trace elements); computer chips can be made. Many of today's manufacturing methods are very crude at the molecular level. While casting, grinding, milling, and even lithography move atoms in great thundering statistical herds, nanotechnology will provide the means to be much more precise - using the fundamental building blocks of nature. Such capability will enable an entirely new generation of electronic and structural products that are cleaner, stronger, and lighter, with a more affordable, extended operating life.



Multispecies Interactions Between Gallium and Arsenic - Notice Formation of Grain Like Structures

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
NOV 1997

3. REPORT TYPE AND DATES COVERED
FINAL 10/01/1997--09/30/1998

4. TITLE AND SUBTITLE FY98 MATERIALS AND PROCESSES TECHNOLOGY AREA PLAN

5. FUNDING NUMBERS
C
PE
PR 9993
TA 00
WU 00

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
MATERIALS AND MANUFACTURING DIRECTORATE
AIR FORCE RESEARCH LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT PATTERSON AFB OH 45433-7734

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
MATERIALS AND MANUFACTURING DIRECTORATE
AIR FORCE RESEARCH LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT PATTERSON AFB OH 45433-7734
POC: MR HERMES (937) 656-9210

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFRL-ML-WP-TR-1998-4000

11. SUPPLEMENTARY NOTES AVAILABLE ON INTERNET:
http://stbbs.wpafb.af.mil/STBBS/taps/taps.htm

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The Materials and Processes Technology Area part of the Air Force Science and Technology (AF S&T) program responsible for developing materials, cost-effective processes, nondestructive evaluation technology and repair / maintenance techniques of advanced materials to support the entire Air Force mission. Over the years many outstanding contributions have been made by this are including superalloys for high-temperature turbine engines; ultra-high purity silicon for infrared detectors; permanent magnets for microwave sources, power generation and conditioning applications; advanced composites for aerostructures; carbon-barbon nozzles and nosetips for missiles; high temperature lubricants and thermal control coatings for spacecraft.

MATERIALS, AIR FORCE RESEARCH, MILITARY APPLICATIONS, COST EFFECTIVENESS, PRODUCTION ENGINEERING, NONDESTRUCTIVE TESTING, STRUCTURES, PROPULSION SYSTEMS, REPAIR, MAINTENANCE, ELECTRONICS, OPTICS, SURVIVABILITY

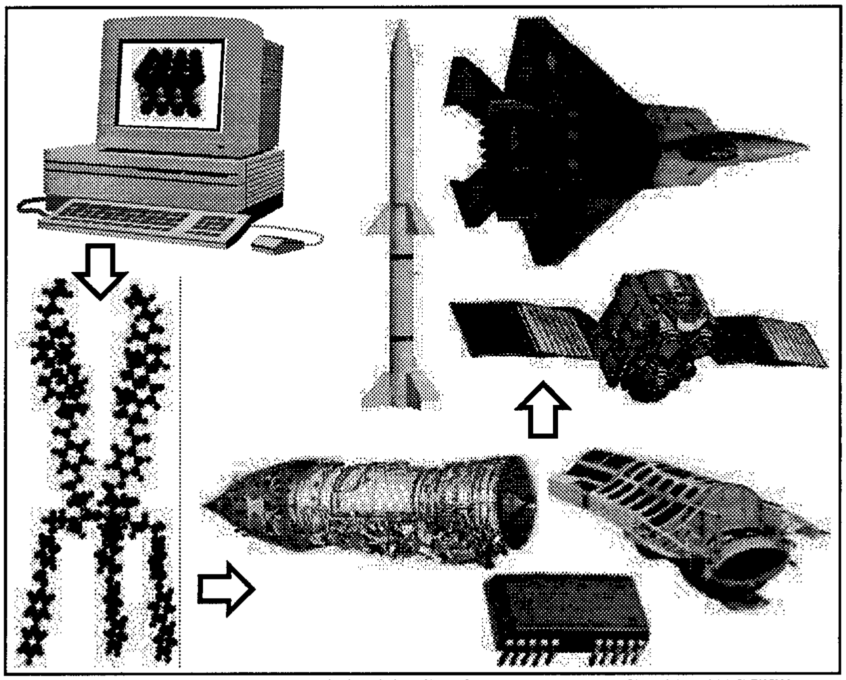
15. NUMBER OF PAGES
33

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

VISIONS & OPPORTUNITIES
Materials & Processes

The Materials & Processes Technology Area Plan addresses materials and processes (M&P) research, development, and support for all Air Force current and future systems. The impact of these technologies is pervasive to all systems. More importantly, M&P often represent the limiting factors in system cost, performance, and risk. The importance of this area is reflected in Department of Defense (DoD) priorities. The Undersecretary of Defense for Research and Engineering, USD/DDRE, has stated that "the top four priorities for DoD Science and Technology (S&T) are Information Technologies, Materials, Sensors, and Affordability." While materials are specifically identified, materials development and processing technologies are also critical elements for each of the other priority areas. The importance of this area is further reinforced by analysis of the *Air Force 2025*, *Spacecast 2020*, Joint Chiefs of Staffs *Joint Vision 2010*, and the Air Force Scientific Advisory Board *New World Vistas* studies. The *Joint Vision 2010* Operational Concepts of Dominant Maneuver, Precision Engagement, Full-Dimensional Protection, and Focused Logistics are all directly impacted by this technology area through the development of M&P for enhanced structures and propulsion systems, advanced electronic and electro-optical devices, laser hardening, and technologies for sustainment. The *Air Force 2025* study identified advanced materials as one of six high leverage technologies important to a large number of high-value system concepts. Also, the *Spacecast 2020* study's top concept was a Transatmospheric Vehicle (TAV) [military spaceplane] in which materials were identified as the most critical technology. Other sources used to determine M&P requirements come from the Air Force's Technology Master Process (TMP) through Mission Area Plans' (MAPs) deficiencies, Technology Planning Integrated Product Teams' (TPIPTs) concepts, Customer Focus Integrated Product Teams' (CFIPTs), and Center Technology Council's (CTC) technology needs. The CFIPT leaders have identified 11 Air Force pervasive technology needs, all of which are dependent upon or impacted by M&P being developed under this area.



"MATERIALS AND PROCESSES TO MEET THE CHALLENGE"

The challenge is to provide better and more affordable materials and material processing support to operations and maintenance, while developing the materials and processes to meet potential readiness problems in 5 to 10 years. The opportunities lie in responding to the needs of aging systems in the near term from which production experience of M&P technology is gained, thus reducing the risk of transitioning M&P technology into 21st century systems. Whether the challenge is aging systems or preparation for next century systems, our vision is to provide "the materials and processes to meet the challenge".

We will develop materials and processes to meet the challenge by:

- Conducting near-, mid-, and far-term, high-payoff M&P research and development, and implementing technologies wherever possible on nearer term modifications/upgrades/sustainment activities.

- Developing M&P technologies directly related to improved maintenance of existing systems that themselves become the next generation baseline for improved sustainability.
- Providing in-house expertise and systems support for the Air Force Product Centers and maintenance and repair centers.

To respond to our customer's needs in a period of downsizing, we will:

- Maintain a world-class research organization in a selected number of M&P areas vital to future Air Force capability needs and be "one phone call away" from national and international experts in other areas.
- Have quality facilities in which to perform the excellent work expected of us.

Our philosophy in achieving the above will be to:

- Continue to make our customers aware of new M&P that solve their current problems or meet their future needs.
- Maintain a cognizance of MAPs and a direct involvement in the TPIPTs to ensure that we can insert new technology when needed into new / upgraded weapon concepts.
- Work with CFIPTs to maintain a balanced program that addresses priority needs across all Product Centers.
- Track Center Technology Council (CTC) technology needs and conduct programs to meet priorities of the Logistic and Product Centers.
- Support future logistics reengineering opportunities to reduce logistic response time and infrastructure through predictive planning tools and the ability to make rapid buys of small lots.
- Advocate M&P to enable *New World Vistas*, *Air Force 2025*, and *Spacecast 2020* concepts.
- Collocate engineers with system program offices (SPOs) to:
  - identify system technology needs for M&P technology planning.
  - identify opportunities in preplanned product improvements (P3I).
  - provide expert M&P consultation.
- Interact with other service science and technology organizations to:
  - exploit opportunities for cooperation.
  - provide technology development leadership in areas where we have the sole expertise or technical lead.
  - avoid duplication.
- Contract with industry to ensure that industry possesses technology essential to the Air Force, and to help maintain a vital industrial base.
- Conduct in-house research in order to:
  - pursue technologies beyond the risk of industry or for which industry does not see a large enough market.
  - pick the right technologies to exploit with industry.
  - be educated buyers of contracted technology.
- Address affordability issues as key evaluation criteria in the development of all materials and processes. Material and processing cost, performance, and risk attributes of affordability will be provided to Air Force users and industry.
- Support areas of special interest: including uninhabited aerial vehicles (UAVs), space, hypersonics including spaceplane / Transatmospheric Vehicle (TAV), and information warfare.

This plan has been reviewed by all Air Force laboratory commanders / directors and reflects integrated Air Force technology planning. I request Air Force Acquisition Executive approval of the plan.

RICHARD W. DAVIS, Colonel, USAF
Commander
Wright Laboratory

RICHARD R. PAUL
Major General, USAF
Technology Executive Officer

CONTENTS

INTRODUCTION
Materials & Processes

BACKGROUND

The Materials and Processes Technology Area, highlighted in **Figure 1**, is that part of the Air Force Science and Technology (AF S&T) program responsible for developing materials, cost-effective processes, nondestructive evaluation technology, and repair/maintenance techniques for advanced materials to support the entire Air Force mission. The strategy for development of Materials and Processes (M&P) Technology follows the DoD S&T strategy to develop superior technology, reduce cost (acquisition and operational), maintain a vibrant research program, emphasize dual-use technology and commercial practices, transition technology more rapidly, and support jointness. Keys to successfully implementing this strategy are to maintain a stable investment in areas over a long period, balance the investments across the R&D process, focus investments on critical operations needs, continuously train scientists and engineers, and encourage innovation and entrepreneurship. The DoD Deputy Director of Research and Engineering, in a 26 Sep. 96 briefing on S&T Investments, identified three technology related problems facing the DoD: (1) Diminishing manufacturing capability, due to materials and critical subcontractor supplied components no longer being available, due to lack of market, (2) Loss of knowledgeable workforce, due to retirement and disintegrating teams, and (3) Reduction in specialized test facilities/handling equipment, due to base realignment, closure, and reduced development. Technology solutions from the M&P Technology Area that address these problems are: (1) Reduced reliance on unique M&P by increasing commonality between space and aerospace systems and with other markets, (2) Reduced reliance on human expertise intensive processes by developing / modernizing modeling and simulation tools and databases, and (3) Reduced cost of maintenance through increased service life of critical components and better failure predictive / inspection capabilities.

Over the years, many outstanding contributions have been made by this area including superalloys for high-temperature turbine engines; ultrahigh purity silicon for very long wave infrared (VLWIR) detectors and other specialized applications; permanent magnets for microwave sources, power generation, and conditioning applications; advanced composites for aerostructures; carbon-carbon nozzles and nosetips for missiles; high-temperature lubricants for aircraft; and missiles and thermal control coatings for spacecraft. Over the past year, this area continued to provide outstanding contributions to the Air Force. Many of these achievements are highlighted under the three thrust areas. Particular noteworthy contributions are: the development and transition of diamond-coated ball bearings that last 100X (100 times) longer than steel ball bearings, the first use of gamma titanium aluminide (γ-TiAl) for the F119 engine inner shroud, a new ceramic matrix composite (CMC) with the potential to increase exhaust nozzle component life by 900%, and successful operational assessment of holographic laser protection spectacles for helicopter crews with and without night vision goggles (NVGs).

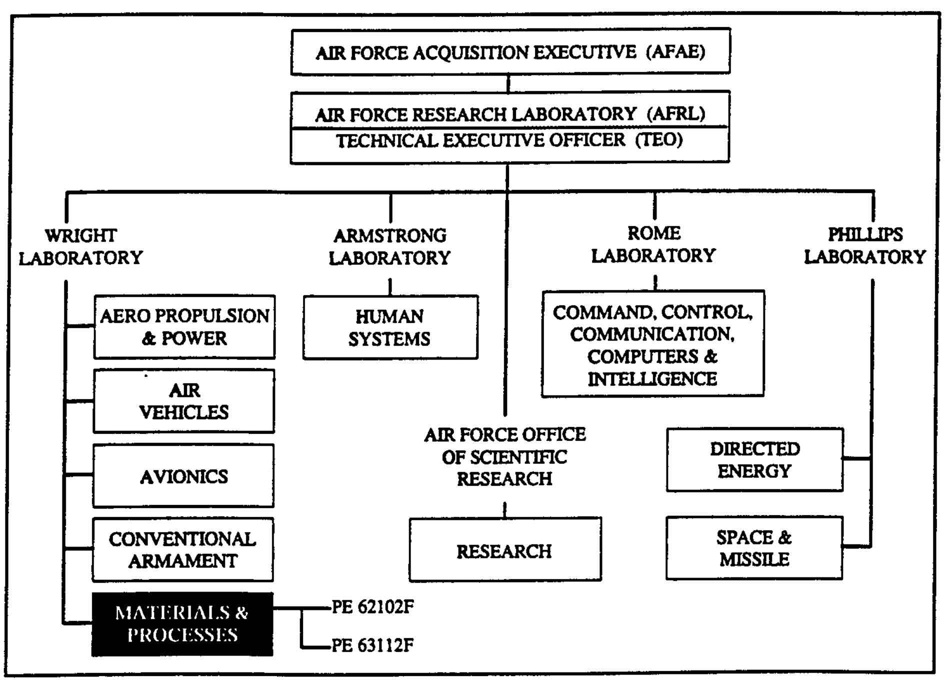


Figure 1: Air Force Science & Technology Program Structure.

Since M&P technology is often a limiting factor in achieving mission capabilities, close working relationships are necessary to define user needs, and to supply the level of user support required. To achieve these relationships, we are actively working within the Technology Master Process and we maintain collocated engineers at Systems Program Offices (SPOs). In addition, we provide quick reaction support to resolve operational field maintenance and other related sustainment problems as they occur. These activities help us to identify technology needs for both current and next generation systems.

The current R&D program is focused on providing the M&P technologies needed for both system upgrades and advanced systems, including propulsion, structures, electronics, optics and electro-optics, all with an emphasis on the affordability attributes of performance, cost, and risk. These system concepts evolve informally through direct-user interactions and formally through the Technology Master Planning (TMP) process. The TMP process has Center Technology Council (CTCs) technology needs submitted by the Air Logistic Centers and Air Force Test and Engineering Centers, Mission Area Plans (MAPs) deficiencies prepared by the Major Commands, Technology Planning Integrated Product Teams (TPIPTs) concepts prepared by the Air Force Materiel Command in cooperation with Air Force users, and Customer Focus Integrated Product Teams (CFIPTs) Technology Needs developed by Wright Laboratory (WL).

To meet systems requirements that drive materials and material processing research and development, the M&P Technology Area is organized into three key Technology Thrust Integrated Product Teams (TTIPT) listed in **Table 1**.

Table 1: M&P Technology Thrust Integrated Product Teams

Technical Thrust Number. And Title
1. Materials and Processes For Structures, Propulsion And Subsystems.
2. Materials and Processes For Electronics, Optics And Survivability.
3. Materials and Processing Technology For Sustainment.

Whether M&P requirements are derived from *Joint Vision 2010*, *New World Vistas*, *Air Force 2025*, *Spacecast 2020*, the Air Force's TMP or from direct interaction with customers at SPOs and Air Logistic Centers (ALCs), the difficult task is in selecting how to distribute limited funds for those needs most critical and/or having the broadest impact across the Air Force. The M&P TTIPTs are structured to meet Air Force capability needs and are reviewed and revised periodically to reflect changing priorities. Thrust 1 is the largest effort and covers development of M&P for a wide range of aircraft, space, and missile applications requiring characteristics such as load bearing, thermal management, lightweight, reduced life cycle cost, signature control and lubrication. Thrust 2 includes electronic and optical materials and material processes to meet requirements for advanced avionics, communications, reconnaissance, surveillance, intelligence and electronic combat as well as electromagnetic materials for transparencies and laser hardening for protection of personnel, sensors, and aircraft and spacecraft structures. Thrust 3 interface with the operational users, provides real-time nondestructive evaluation (NDE) techniques and devices, on-site personnel in SPOs, development of pollution prevention materials and processing techniques, structural and electronic component failure analyses, and transition of M&P technology to the users that develop, operate, and sustain system readiness.

Air Force S&T funds for the M&P Technology Area are shown in **Figure 2**. All funding figures reflect the President's FY98 Budget Request. The program defined in this M&P Technology Area Plan is subject to change based upon possible congressional action. **Figure 3** shows the relative emphasis of these thrusts by distribution of M&P S&T funds.

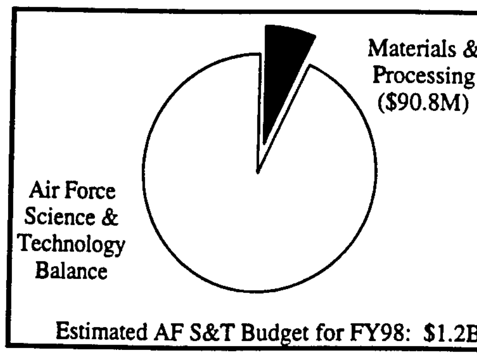


Figure 2: Materials & Processes S&T vs. Air Force S&T

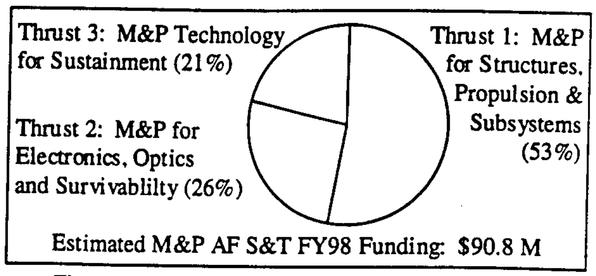


Figure 3: Major M&P Technology Thrust Funding

RELATIONSHIP TO OTHER TECHNOLOGY PROGRAMS.

Relationship to Other Air Force TAPs - Since the M&P Technology Area is broadly based and supports the entire Air Force, it is closely related to many other S&T technology areas. For example, this Area has joint initiatives with the following.

- **Aero Propulsion & Power** Area (WL/PO) for the Hypersonic Technology (HyTech) and Integrated High Performance Turbine Engine Technology (IHPTET) programs.
- **Avionics** Area (WL/AA) in M&P for electronics and electro-optics.
- **Air Vehicle** Area (WL/FI) in structural materials design and validation for composite affordability, advanced high-temperature exhaust materials, high-temperature thermal protection systems, adhesive bonding and joining, composite structures and cryogenic tank materials for reusable launch systems, and aging aircraft.
- **Munitions** Area (WL/MN) for hypersonic missiles and combat UAVs.
- **Space & Missiles** Areas for infrared sensors, structures, coatings and propulsion M&P [Integrated High Performance Rocket Propulsion Technology (IHPRPT) demonstrations].
- **Human Systems** (AL/HR) for crew protection and environmental quality.
- **Research** Area in basic materials.

Areas of special interest in the M&P Technology Area are **space and missile systems, aging systems,** and **uninhabited aerial vehicles** (UAVs). For space and missile systems, this area established a joint investment/program strategy with the Phillips Laboratory (PL) dedicating 20% of its 6.2 core technology budget in support of space and missile systems. This is highlighted by the M&P Technology Area directly supporting PL's focal plane array (FPA) programs: Long Wavelength, Low Background Uniform Mercury Cadmium Telluride (LLUM) and Development of Advanced IR Detector (DAVID). Additionally, the *Spacecast 2020* study's top concept was a Transatmospheric Vehicle (TAV) and the *Air Force 2025* study identified both a piloted single stage to orbit (SSTO) TAV and uninhabited air-launched TAV as high leverage systems. Also, the *New World Vistas* study identified a similar hypersonic air breathing platform/vehicle as one of four major systems. The development of a TAV type vehicle will require (1) advanced structures utilizing high-temperature lightweight materials which allow for long-range long-endurance and high-altitude supercruise; (2) lightweight tanks; (3)a thermal protection system that is durable and maintainable; (4) new engine design and materials; and (5) the ability to inspect these new structures. To focus hypersonic efforts, the Air Force initiated the HyTech program with the primary goal of developing critical enabling technologies for hypersonic systems. In support of HyTech, this area is managing $1M/year to address M&P of propulsion components operating for extended periods above Mach 4. Materials screening and development fabrication processes, joining, inspection and design allowables will be completed in parallel with other HyTech subtasks to support hardware fabrication. Materials testing will be completed by 1999 with full scale inlet and combustor components demonstrated by 2001.

Besides hypersonics/TAV type of concepts for space and missile systems, the M&P Technology Area is developing advanced lightweight materials for space and rocket propulsion and is supporting the Integrated High Performance Rocket Propulsion Technology (IHPRPT) demonstrations. Activities focus on developing the knowledge base necessary to generate high-performance, light-weight, low-cost materials including high-temperature high-performance polymers and novel nanohybrid materials. If warranted by the results of this initial research, investigations toward 3D reinforced composite architectures based on these new materials will be initiated. Critical to the reliable use of these materials in space systems and rocket propulsion technology is an understanding of their structure-property relationship and their behavior in the unique environments encountered during delivery and service in low- and high-earth orbit. Close collaboration throughout these efforts will be maintained with the Propulsion Sciences Division at the Propulsion Directorate (PL/RK).

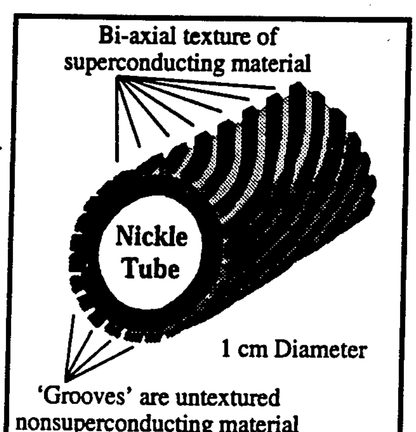
This Area is Actively Supporting IHPRPT.

Life management of aging systems covers a broad range of technologies such as corrosion detection, characterization and protection; durable composite

patch repair of cracked metallic structures; long-life coatings for infrared windows and domes; and alternate heatshield materials and booster inspection methods to enable Air Force systems to be maintained in the active inventory beyond their planned service life. A high priority area for aging aircraft systems is High Cycle Fatigue (HCF) where the M&P Technology Area is addressing life prediction. Existing predictive methods/analytical tools are only valid for perfect materials under ideal conditions.

UAVs will play a critical role in the Air Force's future for they have many advantages, such as minimizing risk to aircrews during target identification/designation. Numerous UAV concepts, as outlined *in New World Vistas, Air Force 2025,* and the various TPIPTs, require advanced capability propulsion systems (higher, faster, farther, longer) and improved stealth technology with the Uninhabited Combat Aerial Vehicle (UCAV) concept having the highest need for M&P development. Longer loiter times, lack of self-defense mechanisms and the use of electro-optic sensors make UAVs highly susceptible to damage/jamming by emerging mid power air defense lasers. Also, affordability is a key issue necessary to ensure the Air Force's success in multiplying force structure with UAVs.

Though the M&P Technology Area is not currently investing in UAV specific technologies, there is a large investment in pervasive technologies that can directly impact UAVs, especially relative to affordability. This pervasive research will allow development of novel M&P concepts to enable survivable materials and structures unconstrained by conventional manned airplane requirements. For example, under a joint WL/ML and WL/PO nano technology program, an ultralightweight wire is being developed for high power generator applications. The wire, a 1 cm diameter nickel tube wrapped with a superconducting thick film filament, is intended to be mounted as part of the armature or stator. This will enable lightweight, megawatt power generation for UAV applications. Also, innovative developments in Nonlinear Optical polymers will greatly enhance the data processing and management necessary to enable the human-computer interfaces inherent in UAVs, as well as conductive polymer development that can replace heavier conventional wiring in UAVs as well as support LO need regarding gap treatments.



A M&P Nanotechnology Program is Developing Ultralightweight Wiring to Actively Control Engines

Industrial Programs - The M&P Technology Area leverages industry investment to maximize return on Air Force investment and ensure critical mass funding levels. Typically, industry investment is more production driven, while Air Force investment addresses research and development needs of new and fielded systems. Thus, this area's strategy is to invest in "high-risk" innovative or breakthrough technologies and to invest in niche M&P technologies for specialized military applications where there is very limited or no commercial development. Thrust 1, M&P for Structures, Propulsion and Subsystems, has demonstrated this strategy by providing technology insertion leadership for organic composites over the last two decades as industry investment has increased. In areas such as laser hardening, industry investment is small resulting in a considerably larger investment being needed within the M&P Technology Area to meet future requirements.

To assist in transitioning M&P technology into industry, this area currently has 25 active Cooperative Research and Development Agreements (CRDAs) with 12 more in negotiation and 13 already completed. The CRDAs underway cover such areas as nonmilitary applications for structural composites, lubricants for commercial applications, exciting new optical and electronic switching applications for Nonlinear Optical (NLO) materials, new commercial materials processing and processing control technologies and new materials process design methods. Of significance has been the application of polymer matrix composites (PMCs) to bridge repair, the development of a prototype composite crutch, the first sale of a new testing device, and the development of low-cost carbon fiber for use in carbon foams.

Also, the M&P Technology Area has four educational partnership agreements with regional schools from which scientists and students are collaborating on research. The universities represented are Dayton, Wright State, Northern Kentucky and Cincinnati.

Additionally, the M&P Technology Area actively supports small businesses through awarding small business set-asides, Small Business Innovation Research (SBIR), and Small Business Technology Transfer (STTR) contracts. This approach leverages M&P Technology Area funding in seeking unique breakthrough technologies to fulfill Air Force techni-

cal and mission needs. The success stories include: a new type of plastic tubing; diamond-coated ball bearings which last 100X longer than steel; significantly improved nonlinear optical crystals for efficiently producing high power laser light; new crystals for high energy laser pulses with improved Q-switching; and carbon-carbon materials for electronics packaging to double reliability. **Table 2** lists the number and total funding of on-going Phase I & Phase II SBIRs for FY95, FY96 & FY97 by M&P Thrust. **Table 3** does the same for STTRs for FY 95 & FY 96. Total on-contract SBIR Phase I, Phase II, and STTRs in FY95 equaled $21,420,127. Awards for FY97 STTRs are still in process as of submittal of this TAP. On average the M&P Technology Area awards 50 contracts per year of Phase I and II SBIRs and STTRs worth $11.2 Million.

Table 2: Summary of On-Going FY95 to FY97 Phase I & II SBIRs by M&P Technology Thrust.

M&P Thrust	No. of On-Going Phase I & II SBIRs	Funding FY95-97
1. Structures, Propulsion and Subsystems	73	$16,304,902
2. Electronics, Optics and Survivability	51	$12,406,487
3. Technology for Sustainment	18	$3,556,282

Table 3: Summary of On-Going FY95 and FY96 STTRs by M&P Technology Thrust.

M&P Thrust	No. of On-Going STTRs	Funding FY95-96
1. Structures, Propulsion and Subsystems	5	$741,286
2. Electronics, Optics and Survivability	3	$499,558
3. Technology for Sustainment	0	$0

International Programs - The M&P Technology Area actively works with international partners by cochairing international symposiums and having 14 international agreements. There are two international exchange agreements (IEA), one for advanced PMCs and their application in aircraft structures and the other covering laser hardening. Under two Four Powers project arrangements, this area is collaborating on tactical laser hardened materials and nondestructive evaluation (NDE). Four Data Exchange Agreements (DEA) exist in the following areas: 1) behavior of advanced fluids and lubricants, 2) composite materials and structures, 3) material measurements and characterization, and 4) materials and processes for military applications. The other six efforts cover data exchange agreements regarding electronic materials, Carbon-Carbon [C-C] composites for dual use applications and C-C ablation models for thermal protection. All agreements cover high priority areas that support related Air Force needs and enable the M&P Technology Area to follow international developments and incorporate these technologies into Air Force systems.

Other DoD and Government Agencies - The M&P Technology Area is thoroughly coordinated through the Department of Defense (DoD) Joint Directors of Laboratory (JDL) Project Reliance and the Technology Area Review and Assessment (TARA) process. Under the Project Reliance's M&P for Survivability, Life Extension and Affordability panel, the Air Force chairs three subareas and cochairs two other subareas. The subareas chaired by the Air Force are Materials for Sensor and Electronic Systems, Laser Hardened Materials and Signature Control Materials. The subareas cochaired by the Air Force are Propulsion (AF) and Power (Navy) Materials, and Operational Support materials where the Air Force leads efforts in propulsion and operational materials while the Navy leads power materials and nondestructive evaluation (NDE). Through these subareas the Air Force supports the Defense Technology Objectives (DTOs) and Defense Technology Area Plan (DTAP) This Area is also actively working with the National Materials Advisory Board and National Science and Technology Council (NTSC) to identify critical national M&P issues. This ensures that critical Air Force M&P are included in the national investment strategy.

CHANGES FROM LAST YEAR

In response to *New World Vistas* and *Air Force 2025* the M&P Technology Area started investigating 4 key M&P related shortfalls regarding Micro-Electromechanical Systems (MEMS). The MEMS M&P needs are (1) ability to operate at high-temperatures; (2) an understanding of failure modes and durability drivers to enable life analysis; (3) surface treatments and coatings to control interface phenomena and degradation; and (4) new M&P to enable novel, very high performance devices. The effort to address these 4 M&P shortfalls is being lead by Thrust 2 (M&P for Electronics, Optics and Survivability) but due to the nature of the problems this effort is jointly managed with Thrust 1 (M&P for Structures, Propulsion and Subsystems).

Due to a general reduction in the S&T budget, a majority of the technical milestones have slipped at least 6 to 12 months.

PROGRAM DESCRIPTION

Thrust 1: Materials and Processes for Structures, Propulsion and Subsystems

The overall objectives of this thrust are to provide new materials and processes (M&P) for:

1) Piloted aircraft, Uninhabited Aerial Vehicles (UAVs), Transatmospheric Vehicles (TAVs), tactical and strategic missiles, launch systems, and satellite structures,
2) Propulsion in all of the systems above and,
3) All Air Force systems nonstructural applications (hydraulic fluids, coolants, solid and liquid lubricants, seals, and coatings).

A roadmap for Thrust 1 is presented in **Figure 4** and illustrates the three major focus areas for Thrust 1. Materials currently under development or transition include carbon-carbon composites and foams, polymer matrix composites, conductive and nonlinear optical polymers, aluminum and titanium alloys, titanium metal matrix composites, nickel based intermetallics, ceramics, ceramic matrix composites and nonstructural materials such as hydraulic and cooling fluids, lubricants, seals and coatings/paints.

USER NEEDS

Carbon-Carbon and Thermal Protection Materials [C-C and TPM] are being developed to meet user needs for improved operational capability of strategic and tactical systems. These materials offer significant benefits including weight savings; dimensional stability; thermal conductivity properties which will lead to higher performance structures and smaller radiators on aerospace systems; lighter and cooler space and aircraft electronics packages; and the historical benefit of high performance in very high-temperature, very high velocity, and extreme thermal environments. A summary listing of C-C and TPM user needs are as follows:

- Lightweight, dimensionally stable, multifunctional space structures that do not outgas.
- Assessment of aging TPM and development of affordable replacements for near-term intercontinental ballistic missile reentry vehicle (ICBM RV) fleet needs and future hypersonic systems.

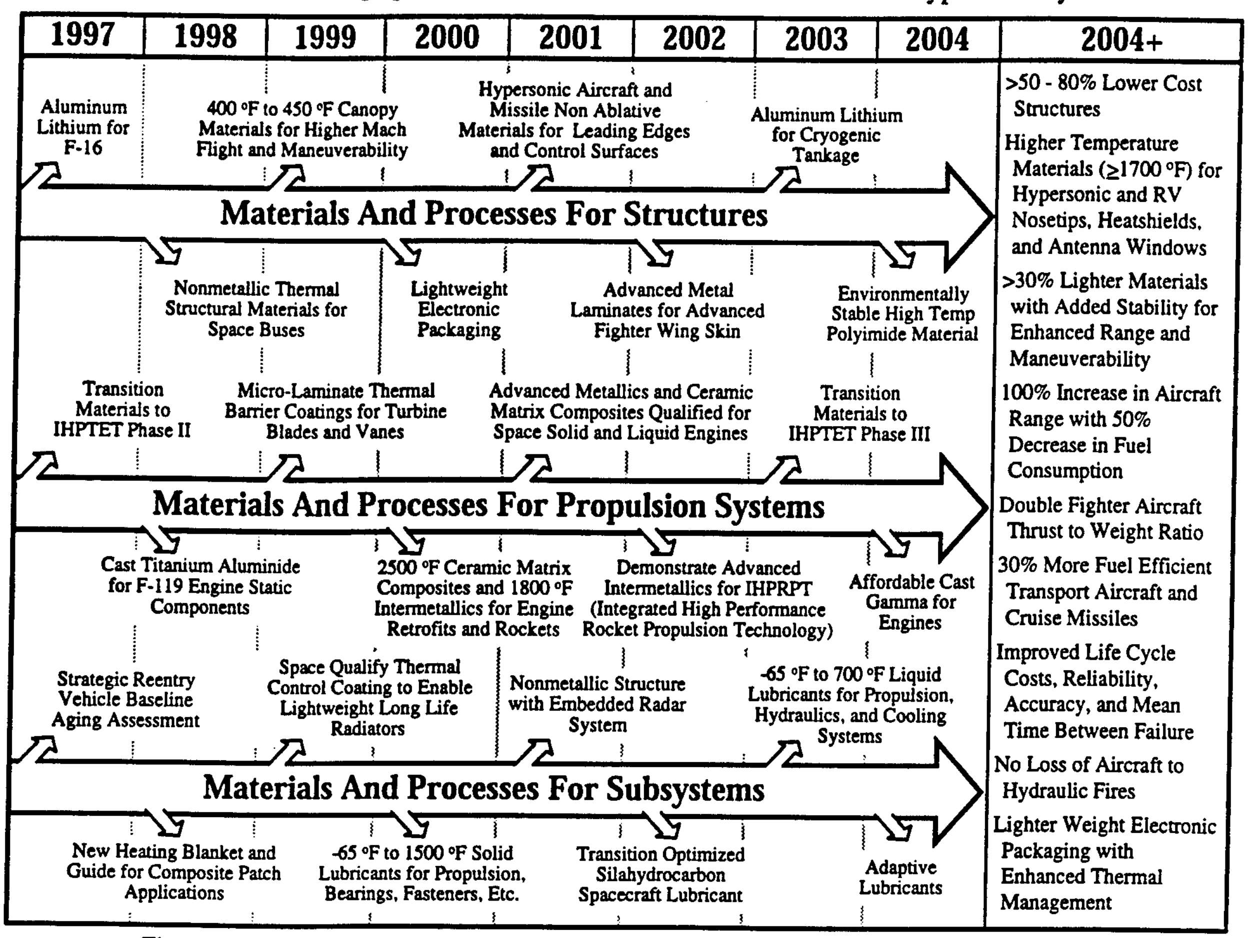
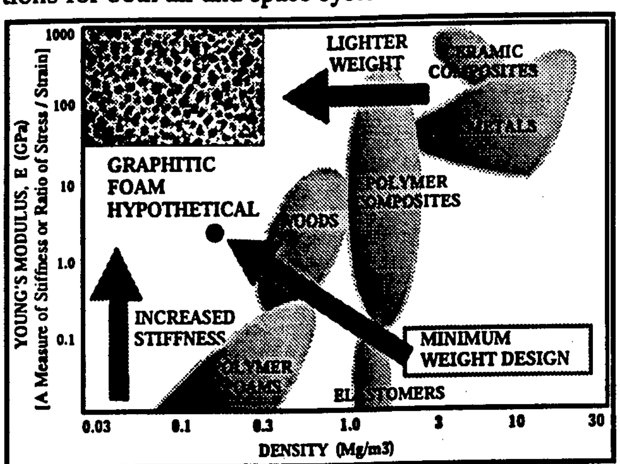


Figure 4: Thrust 1 – Materials and Processes for Structures, Propulsion, and Subsystems.

- High-thermal conductivity electronic packaging, radiators, battery sleeves, and thermal doublers.
- Structures for aircraft heat exchangers which are lightweight with moderate thermal conductivity and have 1000°F temperature capabilities.

Specifically, advanced TPM that are affordable, lightweight, ablation and erosion resistant are being developed to meet requirements such as Presidential Directive 30 which states that nuclear deterrence will be maintained. Aging materials have become a critical concern to the ICBM community. Aging effects are being evaluated with system impacts of aging materials still unknown. Materials will be developed for antenna windows, shape-predictable nosetips, heatshields, and thermal protective reentry materials for environmental stability and ablation. Whenever possible, innovative C-C technology such as thermal planes and battery sleeves will be transitioned to existing and developmental systems, such as the B-1 and F-22. Graphitic foams are also being developed that are extremely lightweight with a very high modulus and have the potential to be a significant breakthrough for low-cost high-temperature applications for both air and space systems.



Goals for Graphitic Carbon Foam

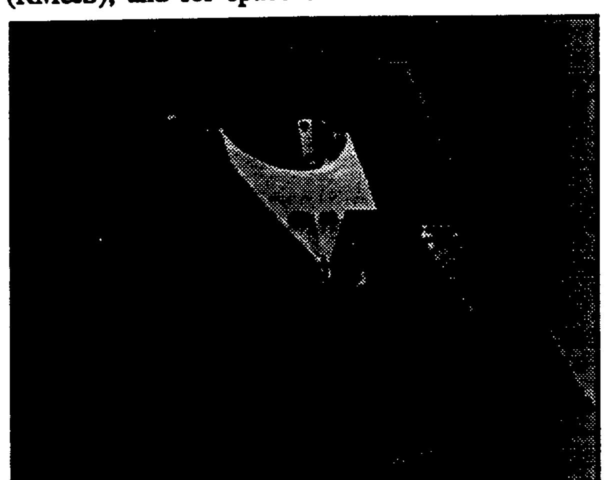
The primary customers for C-C & TPM are the Strategic Deterrence, Aerospace Control, Air-to-Surface, and Special Operation mission areas. This area is coordinated with the Space & Missile Center (SMC), Air Force Space Command (AFSPC), ICBM Systems Program Office (SPO), Deputy Assistant Secretary of the Air Force for Space Acquisition (SAF/AQS), and the Space Force Applications Technology Planning Integrated Product Team (TPIPT). C-C & TPM will be a critical element enabling future spaceplane / Transatmospheric Vehicle (TAV) concepts and Integrated High Performance Rocket Propulsion Technology (IHPRPT) demonstrations.

Polymer matrix composites [PMCs] are being developed to meet user needs for aircraft structural applications including lightweight airframes, control surfaces, aircraft canopies, smart skins, and engine fan blades, frames, and ducts. For space, structural applications include launch tankage, trusses, struts, solar arrays, antenna supports and bus structures. PMCs offer significant weight savings compared to traditional metallic counterparts. Common to these structural needs for PMCs are the needs for:

- Reduce life-cycle costs (LCC),
- Reduce acquisition time,
- Enhanced performance and durability, and
- Technology transition and transfer.

PMCs developed in this area have already met user needs for several systems (F-15, F-16, B-2) providing up to 35% weight savings. When high-payoff low-risk opportunities exist this area will focus on near-term technology transitions (F-22, F-117A, F100-229, F110X, and F119). This technology is strongly endorsed by the F-22 SPO. The F-22, which is a near-term priority of PMC technology, will have approximately 25% of its airframe fabricated from composites. The F-117A trailing edges are being retrofitted with a high-temperature composite developed under this area. The B-2 SPO also is investigating the use of this high-temperature PMCs. Almost all new Mission Needs Statements (MNS) have the need for reduced weight / low-cost structures and nonmetallic composites offer the most cost-effective way to achieve dramatic weight reduction (≈ 25-35%).

The primary focus for PMC development is low-cost structures via more affordable processing, enhanced life prediction predictive capabilities for increased reliability, maintainability, and supportability (RM&S), and for space structures. For affordable



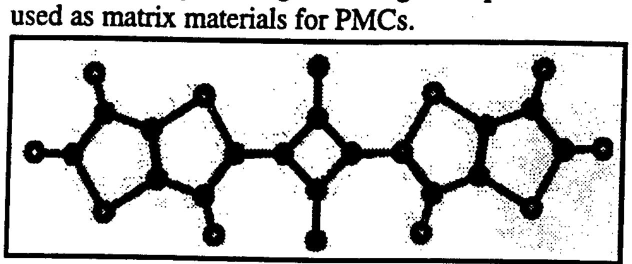
Qualified the Application of Affordable Thermoplastic PMC on the F-22 Fighter, Example Landing Gear Doors

PMC processing, this area is investigating M&P that will dramatically lower the cost of fabrication and assembly of large integrated structures envisioned for the Joint Strike Fighter (JSF) and future aircraft and launch systems. PMC are also improving the thermal conductivity of resin systems typically used in spacecraft. Future emphasis will move towards developing materials that support large space collectors and rocket propulsion requirements.

Farther term efforts include development of nanocomposites that have Metal Infiltrated Fibers (MIF) which exhibit outstanding temperature and mechanical properties *and* also possess electrical conductivities that are 10X better than pristine rigid-rod fibers. Also, because of MIF's unique morphology, its electrical properties will survive numerous bending cycles. Thus, MIF nanocomposites may replace current metal signal wires in air and space craft, thereby, reducing electrical system weight and improving overall system performance.

The primary customers for PMCs under development are the Air Logistics Centers (ALCs); B-2 and F-22 SPOs; and the Air-to-Surface, Aerospace Control, and Special Operations mission areas. Technologies will be transitioned to existing systems at the ALC's and into new / developmental systems, such as the B-2, JSF, (Combat) UAV, and F-22.

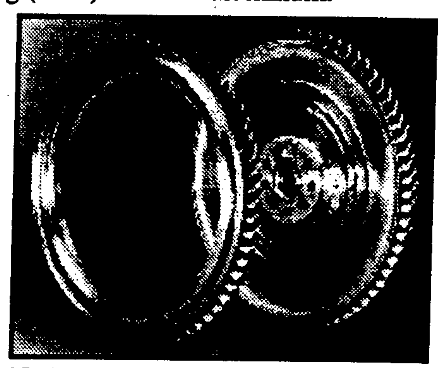
Polymeric materials are being investigated as possible far-term solution to user needs requiring enhanced conductivity and electro-optic capabilities. Because these materials are related to structural polymers, but applied to electronic and optical applications, this area is jointly managed between Thrust 1 and Thrust 2: M&P for Electronics, Optics and Survivability. Conducting polymers offer a far-term very-high-payoff solution to gaps on low observable (LO) aircraft; lightweight wiring to replace copper; lightweight batteries for air and space craft; improvements in light emission for flat-panel displays (FPD); visible signature suppression of aircraft; lower-cost, higher efficiency photovoltaic materials; and improved grounding and charge dissipation when used as matrix materials for PMCs.



The M&P Technology Area Developed the First Soluble Symmetric Ground State Conductive Polymer

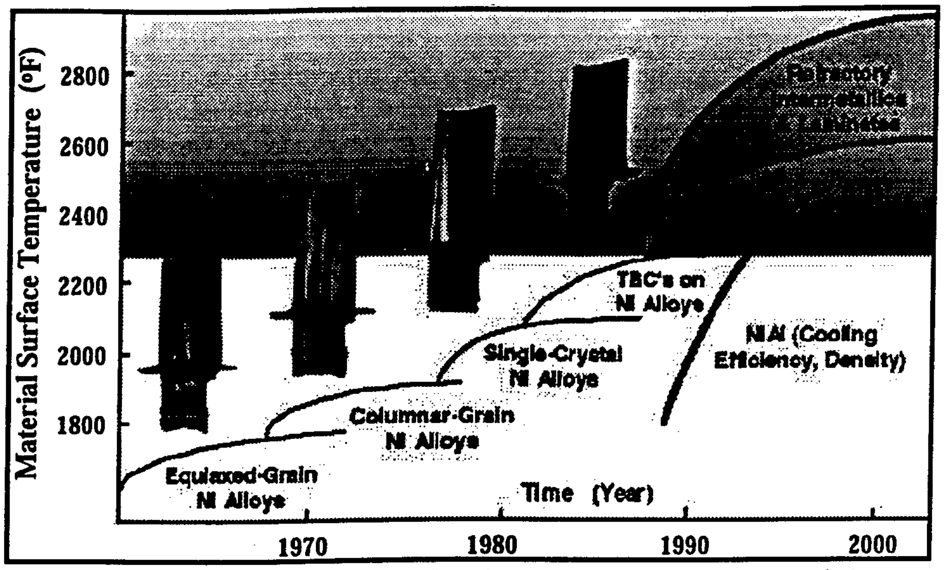
Organic polymers for nonlinear optical (NLO) applications offer the potential of large bandwidth, low cost, the fastest switching speeds of any NLO materials, ease of processing, light modulation at high frequency, low power, and a coherent blue light source for increased data storage. Also, highly transparent polymers are being developed which, when hit with high-intensity laser light, will limit the transmitted fluence to levels required for eye protection. NLO polymers also have demonstrated their potential to be used as ultra high density, 3-D memory storage devices. In the near future, they will be demonstrated in high-speed interconnects for next generation air and space craft and in 2-photon upconversion schemes for solid-state low-power blue laser sources.

Affordable **metallics** are being developed and transitioned to meet user needs regarding efficient and reliable performance in propulsion systems and structures with lower acquisition cost and improved reliability. The focus is to develop affordable lightweight metallic materials that are considerably lighter than conventional aluminum [Al] or can withstand higher temperatures than currently available materials. Applications include lighter aircraft and satellite structural components, more efficient space launch systems, and high-temperature high-performance engine components. The types of metals under development include titanium [Ti] alloys and gamma-phase titanium aluminides [γ-TiAl], titanium metal matrix composites [Ti MMC], niobium [Nb] based and other intermetallics, advanced processing, aluminum-lithium [Al-Li] alloys, and stress corrosion cracking (SCC) resistant aluminum.



Ti MMCs Reduces Bladed Ring (Bling) Weight 50%.

The key customers for metallic M&P are primarily in the Air-to-Surface, Aerospace Control, Special Operation, and Mobility mission areas. Another area with related metallic requirements is the Strategic Defense mission area. The systems which may use these metallics are F-22, F119, C-17, JSF, F-15 and spacelaunch vehicles (reusable and expendable).



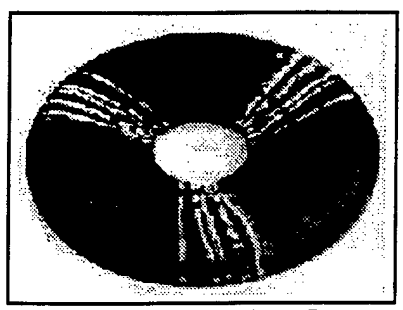
Chronology of Advanced Intermetallic Development for Engine Turbine Airfoils.

This area supports both near-term and far-term user needs. Near-term material development supports current systems with evolutionary improvements and also supports systems having application problems. As an example, this Area has provided technical assistance to the F-22 SPO in evaluating the processing and repair of Ti-62222 in the F-22 aft fuselage. This knowledge will enable the development of procedures for reclaiming parts that would otherwise be lost in manufacturing. Another near-term effort involves Al-Li which offers 10-20% weight savings over conventional aluminum but has not been used extensively because of anisotropic property concerns. This concern has been solved and scale-up of the process is underway to make large structures that will be lighter and equally durable.

Far-term uses are addressed in high-temperature M&P for advanced engine compressor sections. At 1400°F, orthorhombic TiAl MMC offer the best strength to weight of any material. An advanced engine study under the Integrated High Performance Turbine Engine Technology (IHPTET) demonstrator has shown that a 60% component weight reduction can be realized over superalloy disks and blades, while allowing increased rotational speeds and higher temperatures. Essentially all future aircraft systems require improvements in lightweight / low-cost structures, extended aircraft range, and improvements in specific fuel consumption. Lightweight metal alloys will provide modest improvement in weight and range. High-temperature TiAl, however, will help provide revolutionary improvement in military operational capability [fighter with 100% increase in thrust-to-weight (TTW) and range while decreasing fuel consumption 50%].

The upper use temperature of current metals for blade and vane systems is about 1800°F. Because of this temperature limitation, the M&P Technology Area is developing **advanced intermetallics** (and/or refractory metal composite) systems which are capable of applications for temperatures of 2000°F to 2800°F. Typical systems requiring these extreme temperatures are primarily for propulsion systems such as turbine engines and scramjets for fighter aircraft and hypersonic platforms, as well as for launch vehicle rockets. To satisfy these extreme requirements, intermetallics are being developed that have improved oxidation resistance with a balance of low-temperature toughness and high-temperature strength/creep resistance. The present strategy is to maintain a balanced effort addressing the critical intermetallic issues of coatings, process development, micromechanics of failure, and fabrication of components.

Ceramics and Ceramic Matrix Composite [CMCs] are being pursued to replace metal components in fielded and developing air and space systems to meet user needs for greater temperature capability, lower weight, improved durability and maintainability, and reduced infrared signature. The current effort addresses the pacing issues for continued application of CMCs in Air Force systems. Efforts are structured to (1) enable CMCs to be used as preferred spares for turbine engine and exhaust impinged structures (F110, B-2) at the earliest possible time, (2) to be inserted as components for evolving aerospace systems (F-22, JSF, UAVs), and (3) develop CMCs for rocket engines through IHPRPT demonstrations and for other space applications. The primary custom-


Developed CMC Turbine Engine Combustor That Increases Maximum Operating Temperature to Produce More Thrust and Permit Greater Fuel Economy

ers are in the Air-to-Surface, Aerospace Control, Special Operations, Mobility and Strategic Defense mission areas which have opportunities to transfer technology for engine modification/upgrade.

Overriding the development of advanced C-C, PMC, metallic, intermetallic and ceramic materials is **Materials Process Design** which involves the desire to further understand how to process these materials and how to use these materials in advanced designs. Because processing costs can account for over 90% of advanced materials' total component costs, the development of processing technology to reduce the cost and increase the quality of aerospace components is being pursued. Reductions in processing cycle time are also expected. As stated for PMCs the primary focus is on affordable processing techniques to dramatically lower fabrication and assembly cost of large integrated structures. Current metallic efforts are focused on developing low cost titanium castings, improved homogeneity nickel-base superalloy disk processing, titanium and Al-Li mill products, and innovative low cost processes for fiber reinforced metal and ceramic composites. For example, one program is focusing on modeling techniques to better control process variables that are associated with abnormal grain defects in nickel-base superalloy disks. This effort is anticipated to lower scrap rates and lower cost for both the F110 and F119 engines.

Current designs of structures and engines are limited by the understanding of **Materials Behavior and Life Prediction** capabilities. Existing aircraft structures and turbine engines are designed using the Aircraft Structural Integrity Program (ASIP) and Engine Structural Integrity Program (ESIP) methodologies, but there are three disciplines that are not well understood:

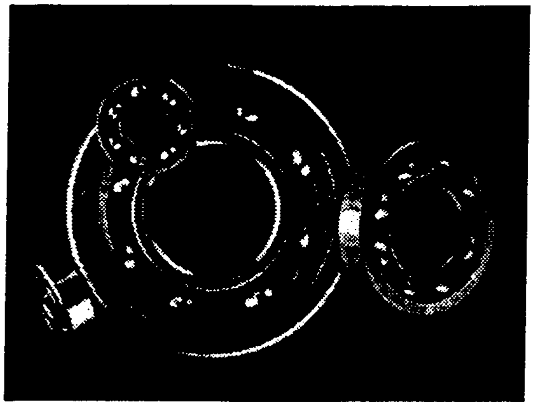
- brittle materials such as intermetallics & ceramics,
- nonorganic composites (metals, ceramics), and
- extreme environments.

In addition, some standardized design methodologies are unable to accurately predict damage growth and failure such as High Cycle Fatigue (HCF) of titanium fan and compressor blades. This issue was cited by the Air Force Science Advisory Board (SAB). This Area's objective is to enhance the understanding of the failure mechanisms with a significant focus on HCF failure.

To improve understanding of HCF the M&P Technology Area is addressing life prediction. The development of a damage tolerant life prediction method for HCF of turbine engine Titanium parts is based on fracture mechanics or other fundamental principles. Current crack inspection methods are only adequate to detect Low Cycle Fatigue (LCF) crack growth, for HCF the critical crack length is below detection capability. Existing predictive methods / analytical tools are only valid for perfect materials under ideal conditions. This Area is also working on the models to account for Foreign Object Damage (FOD), LCF Damage, Creep, Fretting, Corrosion Pitting and Thermal Mechanical Fatigue because failure, due to pure high-cycle low-stress amplitude cycling, is rare. This Thrust is also working NDE methods jointly with Thrust 3, Materials and Processing Technology for Sustainment, to detect 10 - 100 micrometer cracks of parts with variable surface finishes up to possible 1800°F. These efforts directly support titanium applications on F-22.

Nonstructural M&P are being developed to improve or enable the mission performance of Air Force and DoD systems by extending the systems life, improving their performance, or enhancing the survivability of fielded systems. The type of nonstructural materials under development include: advanced hydraulic and coolant fluids; liquid lubricants; advanced tribomaterials / solid lubricants; thermal control coatings for space; space environmental effects research; and aircraft coatings (signature control coatings and paints). These types of materials will provide dramatic improvements for a number of systems such as high TTW engines which require temperatures greater than current lubrication capabilities. Existing aircraft utilize one of two liquid lubricant systems: one that operates -65°F to +400°F and one from +30°F to +600°F. While adequate for most current engines, neither system presently comes close to meeting future temperature requirements. Also, solid lubricant systems capable of meeting the 1500°F requirement of nonman-rated engines do not currently exist, but are being developed.

In high-temperature engine applications (>850°F), fastener seizure is a problem. Pratt & Whitney (PW) estimates that $24 M/yr. is lost due to scrapped parts and increased maintenance time. The F119 engine has 1600 fasteners that experience temperatures exceeding 850°F. The F-22 SPO's Engine Integrated Product Team (IPT) (ASC/YFZ) requested and received materials support in this area, as has the Subsystems SPO (ASC/SMLS) for the TF30, F100, and F119 engines (over 4500 fasteners >850°F). In disassembly overhauls of F100 engines, 20% of hot section bolts have been scrapped. A detailed LCC study of the F100-PW-220 engine indicates a potential savings of $2.4M with the use of antiseize coat-



Developed Hard Coating Solid Lubrication for Bearings that Increased Their Life 20X by Reducing Wear, Friction, Heat and Pitting While Improving Corrosion Resistance.

ings / lubricants. The project, which is advocated by Oklahoma City and San Antonio Air Logistics Centers (OC-ALC and SA-ALC), projects a 94-to-1 return on investment. Similar technology in longer-life lubricants and coatings is being developed to meet another infrastructure technology from SMC. SMC has identified spacecraft lubrication as the performance life limiting issue in moving mechanical subsystems on spacecraft.

This area has already met two recent major system nonstructural materials requirements concerning fire retardant hydraulic fluids and improved electronics cooling fluids and is now transitioning these into fielded systems. A new fire resistant hydraulic fluid (MIL-H-87257) has undergone initial flight testing on the KC-135 and will be flight tested on the B-1 and service tested in 38 KC-135s. The ACC has committed to use the material after validation. Electronic cooling materials have already been installed in B-1 and F-18 systems and have been selected for LANTIRN, Patriot and several other systems with an estimated LCC savings of almost $1B.

Another effort that is being transitioned concerns an Air Mobility Command (AMC) coatings issue which was affecting the survivability of their fleet. This area responded by evaluating the situation, evaluating potential commercially available materials solutions with laboratory and flight testing, and determining the survivability impact. A quick response solution was found in 1 month and complete laboratory and flight testing was accomplished in under a year. The recommendation by the M&P Technology Area is now being transitioned into AMC systems.

Another aircraft coating problem concerns hazardous waste. Paint removal processes cost the Air Force over $1B each year and produce more than 70% of the total hazardous waste generated by the Air Force. An Air Force Paint Task Force was chartered to draft an Air Force Coatings System Strategy and an Air Force Paint Removal Strategy. The coatings system strategy lists the coating system requirements in priority order; corrosion protection, worker health and safety, environmental compliance/pollution prevention, survivability, and appearance. The strategy also lists the research and development needs. The strategies have been coordinated throughout the Air Force and have been signed by all the four-star commanders. The strategies are currently being embodied in a MNS applicable to all aircraft. Efforts have been initiated in this area to satisfy the mid and long-term R&D requirements of the Coating System Strategy.

In summary, nonstructural needs are being met that result in dramatic improvements in gap treatments for low observability, electronics life / reliability, reduction in potential aircraft loss due to hydraulic system fires, and improved survivability.

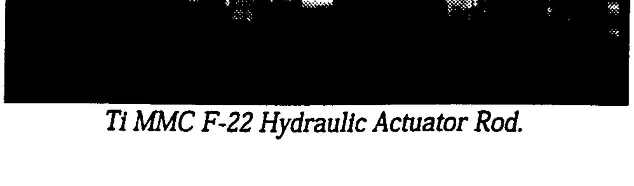
GOALS

The goals of Thrust 1 revolve around improved affordability, maintainability, and enhanced performance of current and future systems as listed below:

- Develop a family of affordable lightweight materials, including metals, metallic and nonmetallic composites, carbon-carbon and ceramics that can provide upgrade capability for existing aircraft, spacecraft and missile systems, and that can meet challenges for new systems beyond the year 2000.
  - To dramatically decrease the LCC of aircraft through 50-80% lower cost structures while improved durability and increasing performance: maneuverability, range, speed and survivability.
  - To meet 1700°F – 2800°F requirements for engines in order to double TTW of 1986 baseline.
  - For spacecraft that are lightweight, environmentally and dimensionally stable (to radiation, atomic oxygen, moisture, temperature) and non-contaminating to meet improved surveillance and communication needs.
  - Advanced M&P for TAV thermal protection systems, structures, tankage & feed systems.
- Provide the fluids, lubricants, seals, greases, coatings, insulations and other nonstructural materials for the subsystems on aircraft, spacecraft, missiles and their propulsion systems.

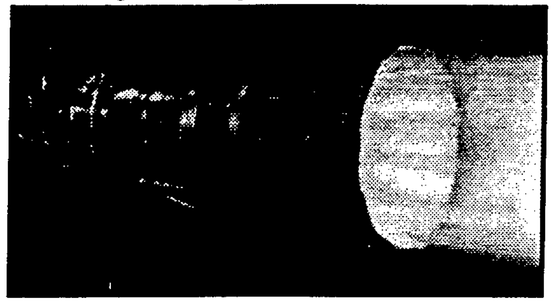
MAJOR ACCOMPLISHMENTS

- Demonstrated low-cost carbon foam with the same compression modulus as aluminum honeycomb.
- Completed testing for alternate/replacement heat-shield and antenna window candidates.
- Transitioned C-C thermal shield and thermal panel for Mars Global Surveyor.
- Validated and transitioned cost-effective thermoplastic composite processing technologies for fighter aircraft structural applications, enabling implementation on F-22 doors and panels.
- Developed model for the first fully 3-D analysis of PMC bonded joints.
- Provided mechanical behavior understanding and statistically significant minimum properties for design and transition of Amercom SiC/Ti-6242, a Ti MMC, to the F-22/F119 program.
- Evaluated a variant of 2% isotropic Al-Li alloy that is weldable using fusion welding techniques for fabrication of cryogenic tanks.
- Produced gamma TiAl inner shroud for F119 engine - first DoD application of this material.
- Developed understanding of HCF and fatigue crack growth behavior of a low-ductility, low-toughness material (γ-TiAl) and the implications on damage-tolerant life prediction and design.
- Demonstrated a full-scale HCF test incorporating a high-frequency (2KHz) magnetostrictive vibrator.
- Published initial HCF evaluations of titanium alloy to provide guidance on resolving HCF issues.
- Provided technical support to transition discontinuously reinforced Al composites to application in the ventral fin and fuel access doors on the F-16.
- Scaled-up the producing of 15,000 lb ingots to produce isotropic Al-Li (AF/C486) thick-plate products for weight reduction of Al components.
- Selected Ti MMC hydraulic actuator rods [Trimarc/Ti-6242, (Ti-6Al-2Sn-4Zr-2Mo)] for up to two flight test engines and for consideration on preproduction engines. Trimarc is 40% lighter than stainless steel saving the F-22 7.4 lbs for and can also be used as actuators for ailerons, flaps and landing gears to save 42 lbs. per aircraft.



Ti MMC F-22 Hydraulic Actuator Rod.

- Evaluated four CMC divergent flaps nozzle components during F110 engine ground test.



Developed CMCs to Increase Operational Life of Nozzle Flaps and Seals by 900%.

- Identified C-130 low-cost ceramic brake insulators.
- Successfully rig tested CMC turbine seal for AR 3007 engine to 1050°F with application UAV.
- Identified ceramics/CMCs for space applications.
- Successfully rig tested CMC liquid rocket engine turbopump stator to 1900°F.
- Converted KC-135 fleet to fire resistant hydraulic fluid, MIL-H-87257.
- Completed toxicological studies of phosphorus tribromide (PBr_3) fire suppressant. Prototype PBr_3 delivered to Flight Dynamics Directorate (WL/FIV) for validation and assessment.
- Developed environmentally friendly process and materials architecture for bearings and fasteners.
- Discovered new deposition process, magnetron sputter pulsed laser deposition (MSPLD), which allows independent control of energy and deposition rate of several atomic species. Permits growth of new metastable materials systems, multilayer, and functionally gradient coatings with unique properties (e.g., low friction, long-wear life, high hardness, increased toughness).
- Demonstrated ultralow solar absorbtance thermal control coating (TCC), made from commercially available oxides, on C-C substrates.
- Evaluated and demonstrated environmentally friendly low-solvent content aircraft LO coatings.

CHANGES FROM LAST YEAR

Thrust 1 had a total of 11 new starts over the past year covering the following issues.

- Aging behavior of RVs & predictive methodology.
- Processing techniques for dimensional control of large PMC structures to lower cost.
- Thermally conductive polymers for thermal management of electronics and satellite radiators.
- Advanced pigments & additives to coatings for signature reduction.

- Alternate gap materials for LO structures.
- Environmentally friendly coatings that are durable / cleanable to lower maintenance cost.
- Life-prediction methodologies for aging aircraft.
- Damage tolerant design of γ-TiAl for engines
- Microstructural characterization for higher-performance materials & lower-cost processing.
- Ceramic fibers for CMCs and MMCs to meet IHPTET and IHPRPT goals
- Understanding formation of texture, microstructural and defects in titanium products.

MILESTONES

- Provide C-C equipment panel and thermal doublers for Earth Orbiter 1 (EO1) spacecraft (98).
- Fabricate 30 lighter weight dimensionally stable materials for space surveillance (98).
- Demonstrate composite patch curing heating blanket for faster, higher temperatures and more uniform curing (98).
- Develop a comprehensive guide for optimal application of fast and low-cost composite patches to metallic aircraft structure (98).
- Transition processing techniques of isotropic Al-Li thick for 10-20% weight reduction from replacement of aluminum in aircraft (F-16 fuselage) (98).
- Transition Ti MMC actuator rods to the F-22's F119 engine (98).
- Predict Ti and Ni based intermetallic turbine engine fan and compressor blades HCF life (98) and establish enhanced design guidelines for gas turbine engines incorporating HCF (ENSIP-2) (01).
- Develop and demonstrate permanent mold casting as a low cost processing alternative to fabricate Ti-6Al-4V hollow fan blades and airfoils for the F119 engine (98).
- Develop and qualify spray forming as a process to produce low cost Ni-base superalloy billet for high pressure compressor disks, high pressure turbine disks, cases and rings (98).
- Demonstrate repair methodology for LO CMC structures and screen NDE methods (98).
- Identify alternate coating corrosion inhibitor (98).
- Demonstrate low-glint canopy transparency coating treatments for Air Force systems (98).
- Provide environmentally compliant high-performance powder-based paints (98) followed by LO aircraft paints (99).
- Transition long-life hydraulic fluid / fuel / oil seals for aging aircraft (98).
- Down select LO gap treatment materials for scale-up (98) and transition to users (02).
- Transition orthorhombic Ti MMC and γ-TiAl for 1400°F engine components (bladed ring) with 50% weight savings over Ni-based intermetallics (99).
- Demonstrate TiAl for > 1700°F HyTech applications (99) for full scale scramjet of inlet and combustors (01).
- Transition advanced lubricants and coatings for spacecraft moving mechanical assemblies (99).
- Alternate/replacement antenna windows with improved durability for aging missiles/RVs (00).
- Demonstrate resin transfer molding (RTM) process for complex shape C-C fabrication (00).
- Qualify Ti-62222 for F-22 (00) and repair welding techniques (02).
- Define and model all physical metallurgical mechanisms leading to abnormal grain growth in Ni-base superalloy disks, thereby controlling defects and lowering scrap rates in F110, F119 disks (00).
- Demonstrate enhanced microstructure, texture and properties to control defects, such as strain induced porosity, in titanium mill product via process optimization and process modeling (00). Transition technology to titanium engine (F110, F119) and airframe (F22, JSF) components (01).
- Demo CMC rotor for limited life engines (00).
- Develop -65°F to 1500°F solid lubricants for propulsion bearings, fasteners, etc (00).
- Transition isotropic wrought Al-Li (AF/C486) welding technique for cryogenic space tanks (01).
- Develop CMCs for IHPTET VI - Phase II (02) .
- Synthesize environmentally stable, highly conductive polymers (02) and transfer into Gap-sealant development program (03).
- Develop materials to allow propulsion thrust-to-weight improvements of 100%, including compressor materials capable of 1700°F and turbine materials capable of 2800°F (TiAl and Ti MMC) (03).
- Demonstrate C-C for avionics and electronics (reduces aircraft weight 540lb and spacecraft printed wiring board count by 40%) (03).
- Transition investment casting modeling and cost reduction techniques for large structural airframe components cast from titanium (03).
- Develop adaptive lubricants (04).
- Provide >1700°F materials (CMCs, C-C, TiAl) for spaceplane, hypersonic weapons, etc... (04).

Thrust 2: Materials and Processes for Electronics, Optics and Survivability

The overall objectives of this thrust are to provide new electronic and electromagnetic materials and material processes for:

1) Electronic, optical, and electro-optic devices and subsystems for aircraft, missile, and space systems.
2) Survivability of aircrews, sensors, aircraft and space systems.

A roadmap for Thrust 2 is presented in **Figure 5** and illustrates the 2 major focus areas for Thrust 2: Materials and Processes (M&P) for Electronic and Optical Devices, and M&P for Laser Protection.

USER NEEDS

As illustrated by Desert Storm, advancements in electronics [radar, IR detectors, communications, and their associated computation systems] have revolutionized warfare and provided the US with an important war fighting advantage. The **M&P for Electronic and Optical Devices** "Spectrum of Applications" extends from low-frequency electronics (DC) through the infrared and into visible light. It addresses all four "S&T Priorities" identified by DDR&E (information technology, sensors, materials and affordability).

The M&P Electronic and Optics Devices effort is balanced between near and midterm needs. Technologies for current systems will be inserted through upgrades / retrofits. There will be technology demonstrations (conducted by users) of concepts enabled by these M&P technologies: IRCM by Tri-service, DARPA and Avionics Directorate (WL/AA) programs; full scale supersonic IR windows by ASC; and high-temperature electronics for engines by the Propulsion Directorate (WL/PO) and Rome Laboratory (RL). Much of the transition will be through industrial partners back to the Air Force. Ultimately, electronics and optical technologies will merge into a single integrated technology for sensing, computing, processing, and communication. Electronic and optical materials & processes will revolutionize weapons concepts by making possible highly sensitive sensors across the entire electromagnetic spectrum; data transmission links with greater than 200 gigabytes/sec. capacity; 3-D data storage with almost instantaneous access; parallel processing of data at breathtaking speeds; ultrahigh performance power generation, distribution, and conditioning; and advanced capability flight control systems. All of these weapon system capabilities are to be developed at reduced cost and increased capability.

However, for the foreseeable future, the Air Force will have very few entirely new platforms; it will depend instead on upgrades which have a very high electronic/optical content. Rather than purchasing entirely new systems, the services will likely undertake electronics-intensive upgrades for major weapons systems in coming years that will drive a strong upgrade market, particularly in avionics. When new systems are acquired they will require the latest state-of-the-art technology to maintain superiority. Their

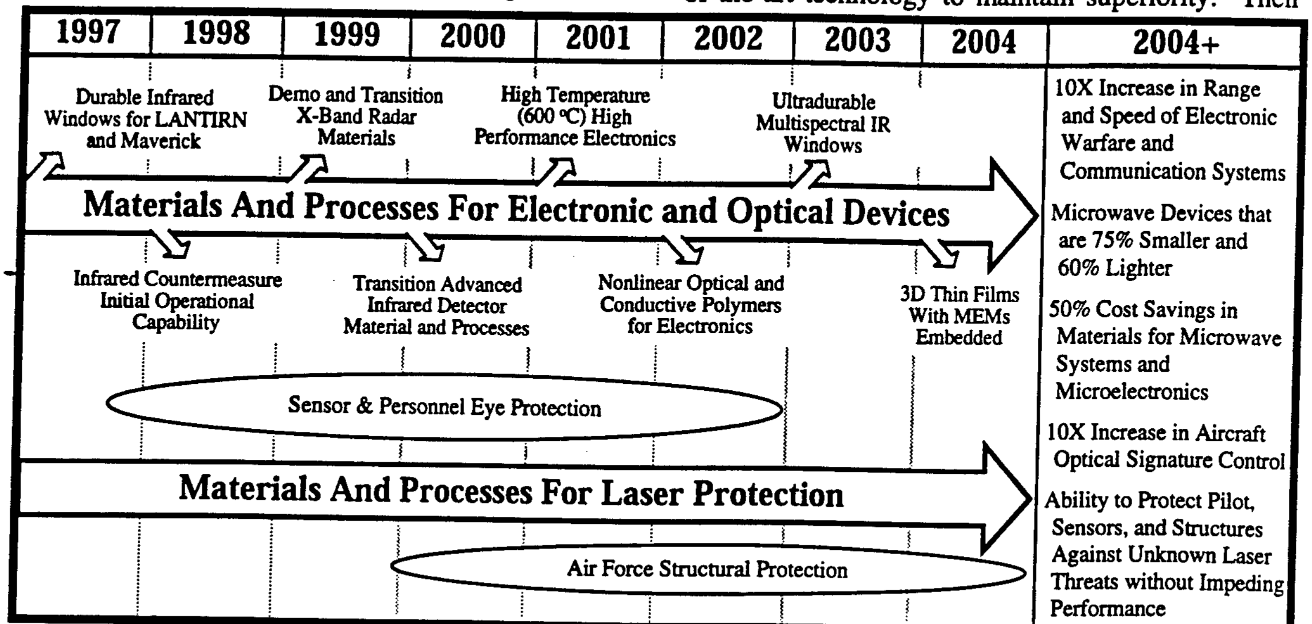
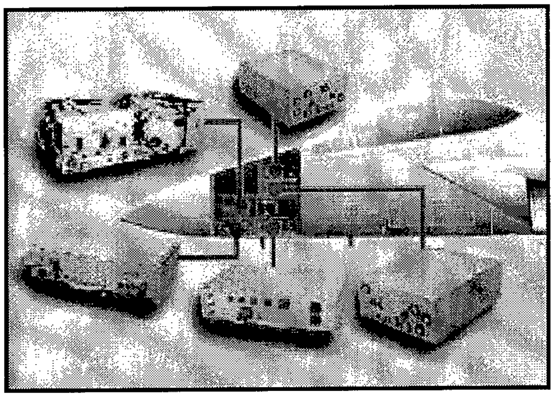


Figure 5: Thrust 2 – Materials and Processes for Electronics, Optics and Survivability.

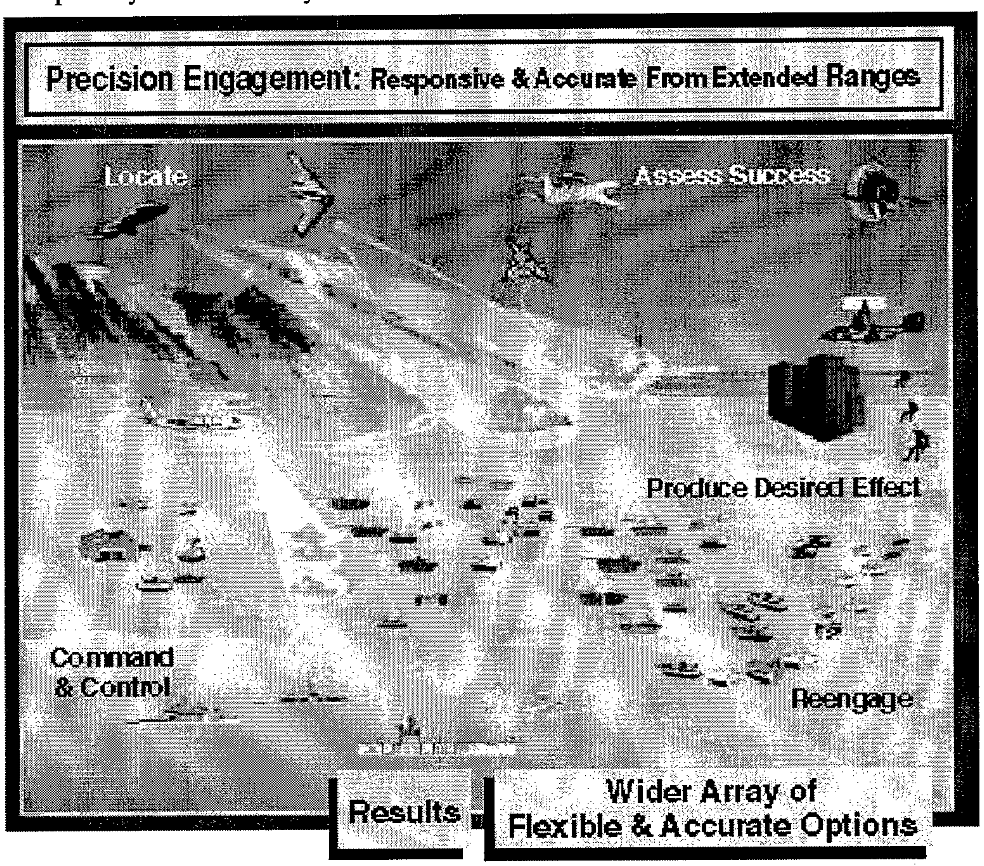


Future Systems Will Depend On Advances In Electronic Materials To Provide Air Superiority.

requirements will involve low-cost signature-control, active/passive countermeasures, advanced radio frequency/infrared/electro-optical (RF/IR/EO) systems, and Low Probability of Intercept/ Detection/ Anti-Jam (LPI/LPD/AJ) navigation and communication systems. Space systems with active or passive surveillance missions have requirements for improved detection capability, faster processing, and LPI/AJ communications. One of the highest maintenance areas for systems is electronics and during systems modification/upgrades a primary driver is to enhance both electronic and avionic capability and reliability (example, replacement of vacuum tubes with high-power solid-state components). These retrofits reduce failure rate and maintenance cost, enhance system capability, and extend the useful lifetime of our aging platforms.

This area has provided many of the materials currently utilized in electronic and optical devices and continues the development of many breakthrough technologies and examples are:

- Rare earth cobalt magnets for virtually every traveling wave tube in every aircraft and satellite radar, communication satellite, and EW system.
- Mercury Cadmium Telluride [MCT or HgCdTe] defect reduction directly transitions to the systems integrators who require extremely high quality materials to meet operability specifications.
- Processing of MCT using vapor phase epitaxy (VPE) enables small lot growth / production capability to meet diverse Air Force applications in a timely, cost-effective manner.
- Zinc sulfide [ZnS], and zinc selenide [ZnSe] IR windows are the state of the art (SOTA) for aircraft and missile Forward Looking IR (FLIR) , IR Search & Track (IRST) and seeker systems.
- Indium Phosphide [InP] to provide higher power / speed than Gallium Arsenide [GaAs] and support the next generation of materials for all weather radar and space based communication.
- Silicon Carbide [SiC] for very high-temperature and high power applications such as engines, more electric aircraft (MEA), uncooled electronics and airborne radars.
- High-temperature superconductors (HTSC) for increases in radar and communication performance.
- E-O polymers for low cost, high performance multichip modules (MCMs), interconnects, space communication, and low probability of intercept.



M&P For Electronic and Electro-Optical Devices are Critical To Joint Vision 2010.

• Nonlinear optical (NLO) materials such as zinc germanium phosphide [($ZnGeP_2$] to enable IR countermeasure (IRCM), wind shear detection, and remote sensing of chemical / biological agents.

Specific activities underway by this Area regarding needs for electronic and optical devices include:

• NLO materials are being developed to meet an Air Force Special Operations Command's Mission Needs Statement regarding IRCMs and an Air Mobility Command's Statement of Operational Need concerning VC-X Replacement Aircraft (AFSOC MNS 001-91, MAC SON 003-90) amongst others. NLO materials provide capabilities, not previously possible for achieving frequency agility and higher power in mid-IRCM laser systems. For example, the success of DARPA / Tri-service laser programs and IRCM programs such as Advanced Threat IRCM (ATICM) are absolutely dependent upon materials developed under this effort.

• Spaced Based IR System (SBIRS) constellation has 3 distinct passive sensor suites. These suites each contain 2 to 4 different wavelength FPAs with correspondingly different detector materials. The M&P Technology Area is addressing these user needs by developing the infrastructure capability for flexible production of single wafer lots.

• Needs were identified during Desert Storm for dust erosion protection of IR windows. Coatings have since been developed that will provide a 300% increase in durability. These coatings are being evaluated on IR Maverick, LANTIRN and F/A-18. Optical quality and durability issues are also being addressed for the current F-117 FLIR rain erosion protection system.

Avionics upgrades for the F-15 will include high speed InP A/D converters for advanced signal processing.

• Advanced semiconductor materials for microwave applications are being developed that will lead to 50% improvement in operating frequency and power handling capability. Wide bandgap semiconductors are being developed to enable more electric aircraft with microelectronic devices operational up to 1100°F temperatures. This materials technology also supports on-engine control technologies and uncooled X-Band radar systems.

The key customers for M&P for Electronic and Optical Devices are in the mission areas of Air-to-Surface, Information Warfare, Aerospace Control, Special Operations, Force Enhancement, Mobility, Electronic Combat, and Space Control.

M&P for Laser Protection are needed to provide new materials and material processes for:

• Aircrew day and night protective eyewear.
• Tactical and strategic E-O sensors.
• Structural protection of aircraft, missile, and spacecraft critical components.

Modern weapon systems use E-O sensors for reconnaissance, target identification, and seeker guidance systems. In addition, many of these systems are augmented by lasers to precisely measure distances and to direct precision guided munitions. The human eye and E-O sensors are susceptible to damage and glare from inadvertent exposure to laser systems. Current hardening technologies are able to selectively excise specific known laser wavelengths from the electromagnetic spectrum through absorptive dyes or reflective coatings. However, the broad range of available laser wavelengths and the proliferation of new wavelengths on the battlefield presents a serious technological challenge. Air Force Major Commands consistently rank laser hardening in the top 10% of all advanced technology demonstrators (ATDs). The need is also highlighted in Mission Area Plans (MAPs), Operational Requirements Documents (ORDs), and other requirements documents.

In summary the M&P for laser protection effort provides validated laser hardening technology options to users, developers, and designers of Air Force systems for the protection of aircraft, sensors, spacecraft, and personnel. Key customers are in the Aerospace Control, Air-to-Surface, Special Operations, and Space Control mission areas. Other customers are in the Mobility, Strategic Deterrence, Force Enhancement, and Rescue mission areas. Key interfaces and shared efforts are maintained with Armstrong Laboratory (AL), the MAJCOMs (ACC, AFSOC) and SPOs (LANTIRN, AGM-130,

AC-130U and others at ASC and SMC). Also, the M&P for laser protection efforts are leveraged with coordinated Tri-Service teams to assess current capabilities and required R&D.

GOALS

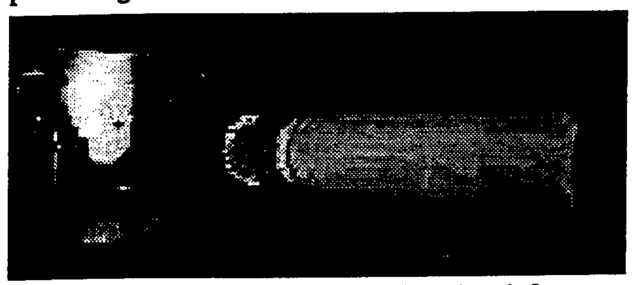
In general, the M&P for Electronic and Optical Devices goal is to develop high payoff electronic and optical M&P for specific Air Force applications while considering two factors. First, maintain a balanced program to address both requirements pull and technological opportunity. Second, leverage commercial electronic and E-O technologies to enable the M&P Technology Area to work niche electronic and optical M&P technologies that are Air Force unique and for which there is no commercial development.

Specific M&P for Electronic and Optical Devices goals regarding radar systems, microwave and microelectronic equipment, IR detectors, photonic devices, and optical processors to meet mission requirements in target acquisition, guidance, communication, EW, and data processing include:

- Transition near-term IR window coatings with >200% improvement in rain and dust durability. Then, develop replaceable protective claddings and externally retrofitable electromagnetic / rain protection followed by development of multispectral missile and aircraft IR window materials that are ultradurable at supersonic speeds: critical to passive IR Sensors or stealth/night operations.
- 10X increase in microwave Transmit/Receive (T/R) module array power without increasing array size through insertion of Silicon Carbide.
- 50% cost savings in materials for microwave and microelectronics systems through increased production yield.
- Infrared (IR) detector materials of high enough quality for use by systems that track cold targets at geosynchronous distances.
- Producible growth technology to meet small lot production requirements across the IR spectrum.
- High-temperature Superconductive (HTSC) M&P for radar and communication to increase dynamic range 10-100X while being 90% smaller.
- Increase wavelength tunable IR laser power output 10X through improved materials.
- Electro-Optic (E-O) polymers with high-thermal stability and large E-O coefficient for high-density photonic switching networks.

Overlying the above goals is a strategy to address cost and availability of E-O materials.

The M&P for Laser Protection goal is to protect aircrews, strategic / tactical sensors, and weapon systems without disruption of their primary mission. Eyes and E-O sensors are sensitive to glare and jamming at power levels many orders of magnitude below damage levels. This necessitates protection with very high dynamic ranges or the combination of multiple protection devices. Protection goals will be achieved through incremental steps progressing from fixed wavelength protection to tunable laser protection. To meet these goals the M&P Technology Area maintains the Laser Hardened Materials Evaluation Laboratory (LHMEL). LHMEL provides the testing facilities not only to evaluate laser protection techniques but also simulation of thermal loading from hypersonic flight or the operation of rocket nozzles. In addition LHMEL has recently ventured into the commercial world with new pollution prevention, surface treatment, environment simulation, and laser processing initiatives.



A Laser Test at the M&P Technology Area's Laser Hardened Materials Evaluation Laboratory (LHMEL).

A series of milestones in incremental steps will lead to protective devices for personnel and sensor protection. For further laser hardening information, refer to the M&P Technology Area Plan Annexes.

MAJOR ACCOMPLISHMENTS

Recent accomplishments by the M&P for Electronic and Optical Devices effort are as follows.

- Transitioned $ZnGeP_2$ materials to enable lasers frequency conversion into mid-IR range.
- Improved SiC single crystal growth processing.
- Transitioned coatings with a 3X durability improvement over current materials for IR windows for F-15, F-16, F-22 and other advanced supersonic aircraft applications.
- Identified electronic material growth processes that enable the coupling of digital & optical capabilities on a single chip.
- Demonstrated enhanced operability and resolution of long wavelength focal plane arrays for space imagery and tracking.

- Advanced computational material science laboratory brought on line.
- Demonstrated low-cost replaceable claddings on prototype IR window.
- Demonstrated flexible growth of MCT IR detector materials and delivered LWIR and VLWIR (128 x 0.28) strategic arrays to PL for further tests.
- Developed bulk SiC for high-temperature avionic applications through the development of very low-defect density processing technique.
- Nationally unique laboratory established within LHMEL to characterize IR materials.
- Laser-based surface treatment techniques demonstrated for improved corrosion resistance and enhanced materials performance. Provides Air Force with option for environmentally friendly chrome plating replacement.
- Versatile IR ellipsometer/spectrometer developed to characterize the complex index of refraction for new optical materials

CHANGES FROM LAST YEAR

In response to *New World Vistas* and *Air Force 2025,* started investigating 4 key M&P related shortfalls regarding Micro-Electromechanical Systems (MEMS). One project was initiated for each MEMS shortfall, and provided with seed funding. Due to the nature of the problems, this effort is jointly managed with Thrust 1: M&P for Structures, Propulsion and Subsystems. Highlights of the 4 projects are:

- Anisotropic etching of single crystal Si enabled MEMS but Si complicates the construction of devices or limits the types that can be fabricated. Micro polymeric composites offer dramatic potential for both simpler and entirely new MEMS.
- SiC may be the best material for MEMS which require high-temperature capability, such as engines. This project has strong collaboration with the Wright Laboratory Propulsion and Power Directorate (WL/PO) and other institutions.
- Enhanced basic physical understanding of material behavior at the micron scale to understand and predict MEMS properties and to identify likely failure modes.
- Wear and surface reactions are major contributors to MEMS device failures and the need for micro/nano-tribology tools to improve the robustness of MEMS interfacial phenomena.

There were also four new starts that supported the existing plan for electronic and optical devices M&P. These new starts cover the following issues.

- Predictable high quality growth processes of SiC for high-temperature electronic applications.
- Multispectral IR detector array M&P to reduce background clutter & enhance image contrast.
- Quantum well structures (p-QUIPS) and light emitting diodes (LEDs) to demonstrate the feasibility of up-converting IR wavelengths into near IR emission for optical readout integration.
- Periodically poled NLO crystals for low-cost high performance wavelength conversion of laser light.

MILESTONES

- Demonstrate direct-write epitaxy of GaAs via holographic masking for use in multifunction electronic chips toward demonstration of combined microwave and digital functions (98).
- Demonstrate processes for the fabrication of defect free SiC surfaces (98).
- Transition high-performance low-defect MCT to LADS and SBIRS Low Flight experiment (98).
- Transition high quality InP bulk material to industry for device manufacturing (98).
- Demonstrate ZGP for IRCM devices (98).
- Demonstrate FLIR system performance of enhanced sensor modules (98).
- Demonstrate replaceable claddings for LANTIRN navigation pod IR window (98).
- Demonstrate full-scale fabrication of F-117 electromagnetic/rain screen for FLIR sensor (98).
- Develop optimum CO_2 laser second harmonic generation crystals for higher power applications (99).
- Transition diamond-coated IR transparencies (00).
- Transition advanced SiC wafer polishing technology to industry (01).
- Demonstrate low-defect high-purity sharp mixed anion hetero interfaces suitable for use in microwave and millimeter wave devices (02).
- Demonstrate MCT for IR detector space (03).
- Demonstrate and transition field replaceable coatings for IR sensor windows (03).
- Transition IR reflective transparency coatings to WL/FI / SPOs for flight testing and incorporation into transparency systems designs (04).
- Demonstrate E-O polymers that survive chip fabrication (solder temperatures) and operation on hybrid electronic/optical chips (02).
- Demonstrate fully implanted SiC through surface gate Static Induction Transistor (SIT) (03).

Thrust 3: Materials and Processing Technology for Sustainment

The overall objectives for this Thrust is to provide support across all Air Force functional mission areas that will enhance the overall reliability, maintainability and supportability (RM&S) of operational systems. Specifically, this Thrust provides:

- Established nondestructive evaluation methods.
  - To detect and monitor service-initiated damage or deterioration.
  - To assure optimum quality in the production of Air Force systems.
- Reduce operations & maintenance costs of weapons systems via enhanced nondestructive evaluation/inspection (NDE/I).
- Ensure rapid NDE/I technology transition to Air Logistics Center (ALCs) via effective coordinated use of advanced development program funds.
- Provide world-class, quick-reaction support to Air Force product centers, ALCs, and operational commands to resolve materials and processing (M&P) related problems in the operational fleet.
  - Provide immediate M&P consultation in response to customer need.
  - Maintain technical expertise & in-house capabilities with state-of-the-art (SOTA) facilities.
  - Provide materials and process evaluation.
  - Provide high quality/reliable failure analysis.
  - Provide reliable engineering solutions/options.
  - Provide repair technologies for composite and metal structures.
- Provide collocated engineers to support System Program Offices (SPOs).
  - Provide immediate consultation in response to customer needs for reliable engineering solutions/options to M&P concerns.
- Develop and transition M&P data critical to AF systems in partnership with the other M&P Technology Area Thrusts.
  - Sponsor technology transitions to SPOs, AF program offices, and ALCs in cooperation with other M&P Thrusts and industry.
  - Identify M&P development opportunities in other M&P Technology Area Thrusts.
- Develop M&P to minimize hazardous/toxic (HazTox) materials in the fabrication, repair and disposal processes.
  - Provide environmentally acceptable technology which allow the AF operators and maintainers to meet mission requirements.
  - Assist in the integration of environmental considerations within the other M&P Technology Area Thrusts and other defense laboratories.
- Create customer satisfaction via aggressively involving customers in the program selection and decision-making processes.

A roadmap for Thrust 3 is presented in **Figure 6** and illustrates the two major focus areas for Thrust 3: M&P for Nondestructive Evaluation (NDE) and M&P for Systems Support.

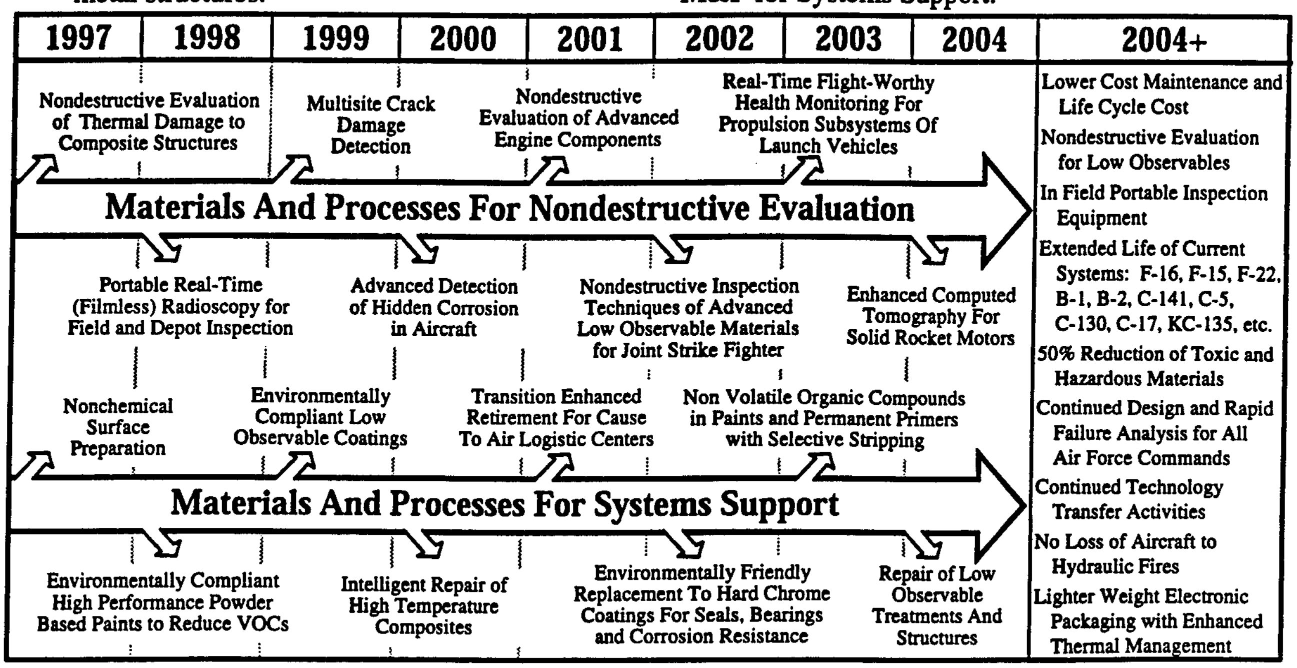


Figure 6: Thrust 3 – Materials And Process Technologies For Sustainment.

USER NEEDS

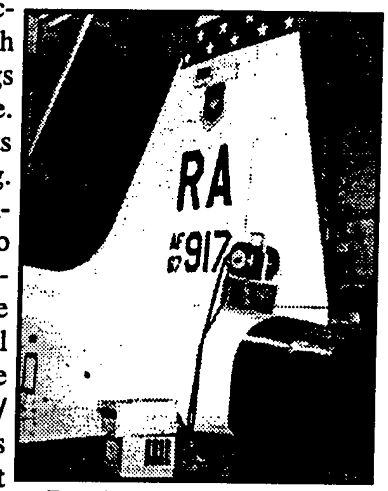
M&P for nondestructive evaluation capability improvements are enabling to ensure optimum quality in design, production, and maintenance of aging aircraft, missiles, aeropropulsion systems, launch vehicles and spacecraft. The results will be 1) increased capability and reliability of currently used NDE/I methods to detect/characterize performance threatening defects (cracks, delaminations, corrosion, etc.); 2) the creation of new NDE/I methodologies; and 3) rapid technology transfer to both Air Force depot and field level applications. The primary customers for the M&P Technology Area's NDE efforts are the Air Force Centers (product, test, and logistics) which report their needs through the Center Technology Councils (CTC) and referenced as Infrastructure technology needs. Of particular interest are the CTC technology needs from the ALCs, which cover all aircraft, aeropropulsion and strategic missile systems. Other customers include those from the Mobility, Air-to-Surface, Aerospace Control, Strategic Deterrence, and Force Enhancement mission areas.

Several top priorities established by the ALCs directly relate to new and novel NDE techniques for a variety of metallic and nonmetallic materials utilized by the operational force today. Also, the need to detect corrosion has become more critical as the Air Force fleet ages. Nearly all types of Air Force systems are in service longer than originally intended, including fighter, bomber, and transport aircraft, as well as propulsion systems, missiles and avionics systems. The KC-135 is limited in its economic life extension due to the effects of hidden corrosion within the aircraft's aluminum structure. Also, corrosion preventive treatments are being eliminated due to environmental concerns, so the need to detect incipient corrosion will become increasingly more important. Incipient corrosion and crack detection are keys to structural airframe life management through the Airframe Structural Integrity Program (ASIP). Inaccessible areas necessitate novel NDE/I methods. Higher resolution NDE/I methods will allow earlier detection for remediation. Multiple subcritical cracking is forcing large area assessment capabilities.

Developed Mobile AUtomated Scanner (MAUS).

X-ray is one of the Air Force's most widely used NDE methods. Currently, the Air Force uses over $100M of industrial X-ray film per year. Current X-ray processing involves hazardous waste, coupled with long-term film storage costs. Technology under development offers enhanced, real-time high-resolution methods with the added advantage of being able to process and store the data electronically. The M&P Technology Area has focused its attention on improving x-ray source and detector technologies in order to improve resolution, reduce costs, and improve recognition of critical flaws.

Computed tomography (CT) is an advancement in X-ray methods which offers unique advantages, but is very expensive and, to date, has found greatest application in large solid rocket motors. However, CT enables the possibility of reverse engineering of replacements for older components which may no longer be in production and for which engineering drawings may not be available. CT also supports rapid prototyping. The M&P Technology Area is also looking at new methods for increasing the resolution of critical inspections in the case / insulator / liner/propellant areas of large solid rocket motors for ballistic missiles and space launch systems.



Developing Real-time High Resolution X-ray Methods that Eliminate Hazardous Materials

New NDE techniques are being developed to improve the above capabilities, as well as to prepare the Air Force to inspect the unique architecture and complexities of low observable (LO) structures and surface treatments. These goals will only be achieved by rapid technology transition to both Air Force depot and field-level applications.

The Air Force has experienced increased use of composites and LO in aircraft (F-117, B-2, F-22, C-17). These materials are now being used in large area primary and secondary structures. The potential

for impact damage necessitates the inspection of the entire surface of composite structures. To address this issue, the M&P Technology Area has developed and is demonstrating and transitioning to the depot and field-level maintenance areas a hand-held, semi-automated scanning device called the Mobile AUtomated Scanner (MAUS). In addition, noncontact laser-based ultrasound (LBU) is being developed to address the need to inspect complex geometries. LBU will allow further automation and reduced cost in inspecting composite structures.

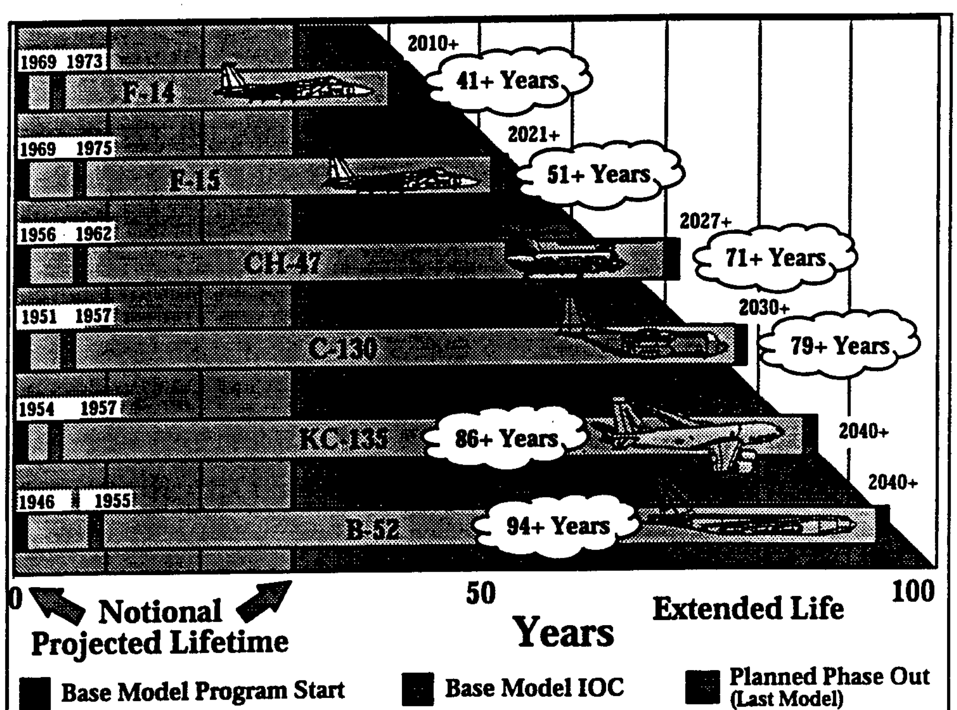
Techniques are also being investigated to inspect multilayer / multimaterials such as those in low observables (LO). Key to implementing LO systems is the ability to verify structural integrity *and* electromagnetic integrity. The principal objective of this effort is to develop fundamental capabilities to NDE the salient properties of idealized structures / materials. NDE/I developed here will be refined for specific applications to decrease maintenance costs of LO systems and increase availability of these high-value assets. The program is oriented toward ultimately developing a portable, multi-spectral (radar, infrared, moisture, heat damage, etc.) hand-held unit suitable for field or depot use.

NDE techniques to evaluate advanced M&P are also needed to support the systems of the future. New materials such as metal and ceramic matrix composites will be fielded in the next few years, and inspection methods will have to be made available. In particular, NDE methods will be needed to detect fiber/matrix interface and damage assessment in these new materials. Some solutions this Area is currently exploring are ultra-fast pulsed laser-generated ultrasonics and scanning acoustic microscopy of advanced materials.

In addition, NDE can be used to perform materials characterization during manufacturing to enhance processing. For example, in polymer matrix composites cure optimization and process control could be achieved with advanced sensors for data acquisition. Also, reusable components for launch vehicles and higher demands for vehicle reliability will require new technologies in embedded vehicle health monitoring systems. The M&P Technology Area is also pursuing advanced NDE research in these areas.

The **M&P for Systems Support** effort develops and transitions support capabilities, information, and processes to resolve system, depot and field related materials problems and to conduct failure analysis of aerospace components. A specific focus is to provide materials solutions to support usage of systems beyond their designed service life. This Area maintains a database to accelerate transition of materials to aerospace systems and maintains reference handbooks for materials repair of aircraft structures.

Air Force product centers, ALCs and operating commands require quick-reaction consultation and engineering support in the areas of structural and electronic materials evaluation. In response, the M&P for Systems Support effort is often involved with the "here and now" of Air Force needs and thus, supports electronics and structural-related crash investigations. For example, engineers respond "immediately" to mishaps and will provide engineering assessments within 72 hours to any serious operational problem caused by a materials reliability and maintainability issue. To provide this capability



Thrust-3, Materials & Processing Technology for Sustainment, is Critical to Projecting Air Force Aircraft Planned Use Significantly Beyond their Designed Service Life.

the Systems Support effort maintains eight in-house laboratories: Electro-Static Discharge (ESD), NDI, structural failure analysis, electronic failure analysis, corrosion engineering, coatings & surface preparation, materials compatibility test and evaluation, and mechanical test. The newest of these is the ESD facility which provides technical support to field and SPO activities through ESD protective material and process evaluation. The scope of the work covers ESD damage prevention to electronic devices and aircraft structures as well as ESD energy analysis related to explosives and mishap investigations.

In addition to co-locating personnel within SPOs to provide M&P support to new weapon system acquisitions, the M&P Technology Area operates three remote offices: the Air Force Corrosion Program Office (CPO) at Robins AFB, the AF Advanced Composite Program Office (ACPO) at McClellan AFB, and the AF NDI Program Office at Kelly AFB. The offices execute a corporate AF sustainment mission by providing engineering support to Major Commands (MAJCOM) operational field units and the ALC's. They are chartered to ensure the Air Force has a viable program in corrosion and NDI, and can support advanced composite structures and components in the field. These offices support the M&P Technology Area by assisting in the transition of technology and acting as a field liaison between the Air Force operating commands and the field. In conjunction with the CPO and the coatings / surface preparation laboratories, this Area also operates, by charter, the Air Force's Coatings Technology Integration Office (CTIO). The CTIO is the Air Force's single source for coatings integration activities including all paint and depaint related processes. The CTIO is responsible for the scale-up, prototyping, and qualification of new coating systems suitable for direct application by the field.

Specific Systems Support activities to meet user needs regarding corrosion, engineering & design data, accident investigations, repair and pollution prevention are as follows.

Corrosion is a significant user concern and this Area is investigating corrosion prevention techniques for both aerospace and nonaerospace applications. The development of corrosion prevention techniques focuses on well established technologies early in the development of aerospace systems and a thorough understanding of corrosion control key elements: component design, material & process selections, manufacturing practices, and system maintenance. Fully developed surface preparation and coating materials are evaluated for acceptable performance characteristics and as viable substitutes mandated by environmental regulations and policies. In a related effort, the M&P Technology Area also uses an in-house facility to provide a unique test capability for determining rain erosion effects on materials during mach 1.2 to 1.5 flight.

In response to user requirements for timely evaluations of materials properties, in-depth data analysis, and practical engineering solutions for Air Force weapon systems, this Area provides engineering & design data. The M&P for System Support effort performs extensive mechanical property testing and duplication of in-service loads, environments and component configurations for design data and evaluation efforts. The primary focus of the effort is to quickly obtain mechanical property data necessary to solve materials problems in Air Force systems and advise on material selection for new systems, system upgrades or repair of existing systems. To expedite the orderly transition of new technology to Air Force systems, this area also evaluates new materials and processes and develops engineering data, application criteria and specifications for their use. In addition this program maintains the DoD leadership for development of the Aircraft Design Handbook, MIL-HDBK-5. Other handbooks have been sponsored by this organization such as the Damage Tolerance Handbook, MIL-HDBK-17, Electronics Failure Analysis Handbook and ESD materials and procedures for the Air Force.

This Area supports accident investigations, failure analysis of metallic and composite components, and the analysis and development of repair procedures for failed aerospace components. Experts maintain SOTA knowledge in the areas of welding / soldering / brazing, life prediction / corrosion / NDI, as well as depot and field-level repair procedures. For composites this includes developing supportability processes

Demonstrated Permanently Bonded Composite Patches to Repair Aircraft Metal Skin and Structure.

and equipment to increase utilization. This includes repair technology, developing fundamental understanding of heat damage, as well as transitioning/transferring patch technology throughout DoD and industry. This effort has helped establish guidelines and criteria to ensure the successful repair of both composite and metallic structures. Also, the M&P Technology Area also provides consultation in the areas of hydraulic and coolant fluids, lubricants, seals, and elastomeric materials.

The entire Air Force is required to reduce or eliminate hazardous waste. In response, M&P for Systems Support has pollution prevention efforts focused in four development areas. First, is to replace current cleaners and degreasers with chloro-fluoro-carbon (CFC) free cleaning systems while reducing the use of volatile organic chemicals (VOCs), ozone depleting chemicals (ODCs), acids, and bases. Second, is to research new methods to make metallic processes such as metal plating, metal removal, and chem-milling more environmentally friendly by reducing the use of cyanides, chromium, lead, copper and nickel. Third, is to develop new methods of painting and paint removal which eliminate isocyanates and chromates. Fourth, this Area develops new processes to enhance preparation of metal surfaces for bonding and other operations in order to help eliminate the use of strong acids or bases and chromates. These four development areas are coordinated with the Environmental Quality Thrust executed at the Environics Directorate. Finally, this Area has taken the lead to implement and coordinate the overall Air Force coating strategy and specifically execute the near-term technical program for coatings.

In summary, the M&P for Systems Support effort is being done to meet needs in managing aging systems and to ensure that engineering processes are available for the Air Force to minimize the use of HazTox materials. By so doing, this area assists in solving problems with existing materials and manufacturing methods and helps to reduce the risk of improper structural designs utilizing advanced materials and to avoid improper manufacturing process.

GOALS

The M&P for NDE goal is to develop full spectrum NDE technology covering:

- Materials characterization during materials development and component design,
- Process sensing during fabrication,
- Inspection during assembly, and
- In-service NDE techniques:
  - for hidden corrosion.
  - to inspect low observable structures for electromagnetic integrity.
  - that can identify areas of multiple small cracks that together constitute structural integrity concerns.
  - for 40X increase in speed of inspecting large areas of composites (from 5 to 200 ft2/hr).
  - with improved automated processing of NDE data for rapid assessment of defects.
  - to characterize high cycle fatigue.

This full-spectrum NDE development will support military systems throughout development, acquisition and operation, as well as being an integral part of engineering and science curricula.

The M&P for Systems Support goals include:

- Maintain a quick reaction response of less than 72 hours to support critical materials and process related problems in the field.
- Provide collocated engineering support to major weapon SPOs.
- Develop environmentally friendly M&P to reduce hazardous and toxic substances used in Air Force operations by 50%.

MAJOR ACCOMPLISHMENTS

- ALCs, Army and Navy successfully evaluated Mobile Automated Scanner (MAUS III).
- Developed C-141 weep hole, crack-detection method.
- Demonstrated feasibility of portable IR Directional Reflectometer.
- Demonstrated prototype of megawatt resonant sensors and instrumentation for detecting heat damage and moisture in composites.
- Demonstrated High-Resolution, 3-D Computed Tomography inspection of critical regions of large solid rocket motors.
- Demonstrated high-resolution, Real-Time X-ray Radioscopy on B-1B horizontal stabilizer.
- Demonstrated lab-scale neutron activation corrosion characterization technology.
- Corrosion Control & Coatings.
  - Established a universal coating system desirability analysis methodology and database.
  - Assessed probability of corrosion from fire suppressant HFC-125, a halon replacement.
  - Conducted feasibility study for applying commercially available corrosion prevention compounds to exterior of C/KC-135 aircraft.

- • Evaluated F-16 mounting standoff fitting for cockpit instrument lighting transformer.
- • Characterized aluminum-lithium alloy for F-16.
- • Evaluated corrosion of C-17 life raft grommet.
- • Completed assessment of commercial coatings systems for aircraft protection.

• Engineering and Design Data.

- • Validated synthetic aperture radar radome modification for open skies aircraft.
- • Developed design data test capabilities for carbon matrix composite materials.
- • Completed preliminary evaluation of laser shock-peened titanium materials.
- • Verified damage tolerance characteristics of Al-Li alloy 2097 for F-16 bulkheads.
- • Assessed high-temperature mechanical properties on new soft magnetic materials under consideration for more electric aircraft initiative.

• Materials Engineering.

- • Developed and optimized field-level composite repair kits for evaluation.
- • Evaluated corrosiveness of F-22 short-term hydraulic component support.
- • Provided M&P and repaired several F-16 aircraft using composite patching technology.
- • Analyzed B-2 hydraulic fluid contaminates.
- • Analyzed F-22 avionics coolant.
- • Demonstrated capability for continuous monitoring of adhesives' "degree-of-cure" during on-aircraft processing.
- • Developed draft overview document for bonded composite repair of metal structure (CRMS).
- • Applied bonded composite patches to C-17 full-scale durability test article in cooperative effort with Flight Dynamics Directorate (WL/FI), USAF Academy (USAFA) and C-17 SPO.

• Repair Technology.

- • Qualified lightweight sealant for F-22.
- • Developed ultraviolet-cured fuel-tank sealant.
- • Performed materials compatibility testing of JP-8+100.

• Materials Analysis.

- • Conducted C-21 mishap materials assessment.
- • Identified AWACS aircraft radar failure source.
- • Identified countermeasures decoy failure source.
- • Conducted Barkhausen noise analysis on F-16.
- • Assessed material development for F-22 casting development program.
- • Assessed life extension of F-16 canopies.
- • Provided measurement and analysis capabilities for (Gunship) thermal target reduction.

• Pollution Prevention.

- • Developed environmentally friendly Sol-Gel surface preparation process.
- • Constructed a prototype carbon dioxide / ultraviolet (CO2/UV) fluid cleaner.
- • Built a prototype super critical fluid cleaner.
- • Demonstrated an advanced nonchromate treatment to provide corrosion resistance and surface hardening in aircraft structural materials.
- • Transitioned Anti-icing fluid to industry.
- • Demonstrated improved nonhazardous cleaning techniques for liquid oxygen lines and solid-state electronics.
- • Completed assessment of pollution prevention needs and possible technology solutions.

• Provided technical assistance to SM-ALC to transition Laser Ultrasonic Inspection System (LUIS).

• Provided technical support concerning welding and NDI procedures to F-22 SPO during their Critical Design Review (CDR).

• Provided critical data to help solve fatigue problems identified in F-16 bulkhead.

• Provided quick-response engineering solution to solve F-15 fuel leakage problem.

• Transitioned MIL-H-87257 Hydraulic Fluid.

• Developed integral vacuum bag/heat blanket to accelerate drying of composite (B-2 exhaust lip).

• Developed environmentally friendly Sol-Gel surface preparation technology.

CHANGES FROM LAST YEAR

Under NDE, there were three new starts over the past year covering the following issues.

- In-service NDE of multispectral LO structures.
- Two exploratory development programs in NDE for new techniques to inspect structures for corrosion, multisite cracking, bondlines, repairs, etc..

Under M&P for Systems Support there were significant impacts regarding both the life management of aging systems and pollution prevention. Some of the new efforts involve in the following.

- Five pollution prevention projects: 1) Laser based chrome plating replacement techniques, 2) Replacement paint stripper of landing gear, 3) Hydrogen embrittlement, 4) Characterization of environmentally acceptable thin-films coatings as replacement for chrome, 5) Nonchromated conversion coating assessment.

- Designs for composite patch repairs and a patch repair handbook for depot engineers.
- Intelligent high-temperature composite and adhesively bonded repair system utilizing new heating blanket concepts to reduce temperature variations.
- Initiated enhancement of the inspection methods, equipment and processes for use in the Retirement-For-Cause (RFC) and Engine Structural Integrity Programs (ESIP) at SA-ALC and OC-ALC, respectively, to inspect gas turbine engine disks for the F100 and F110 engines.
- Enhanced C-scan corrosion detection image analysis tools for OC-ALC.
- Initiated review of LO materials programs and established focal point for manufacturing and field supportability issues.
- Refocused pollution prevention program providing more emphasis on near term issues and solutions.
- Initiated development of Composite Repair of Metal Structures Handbook

MILESTONES

- Continue 72-hour quick-reaction solutions to field / depot material related problems (Annually).
- Transition IR handheld directional reflectometer NDE designs to F-22 (98).
- Transition MW resonant sensors to F-117, Holloman Air Force Base (98).
- Demonstrate feasibility of LO verification point inspection tool technology in a hand tool format (98) and transition to SPOs (99).
- Transition NDE/I technologies for characterization of fiber-reinforced composite structures (98).
- Demonstrate initial NDE/I technologies for the LO materials and structures characterization (98).
- Characterize effects of atmospheric pollutants on mechanical behavior of aluminum alloys (98).
- Establish corrosion assessment framework for estimating structural life of operational aircraft (98).
- Establish environmentally compliant coating (98).
- Provide improved performance, environmentally friendly metal surface preparations (98).
- Distribute guidelines for bonded composite repair of metallic structure (98).
- Develop new heating blanket for faster composite patch curing, which heats more uniformly and produces higher quality patches/bonds (98).
- Evaluate (98) and transition (99) improve environmental durability nonchromate coatings for corrosion resistance and surface hardening.
- Transition nonhazardous cleaning techniques for liquid oxygen lines & solid state electronics (98).
- Develop material replacement for rigid-flex printed wiring boards (98).
- Transition improved composite repair techniques of metal structures and characterize field-level repair needs of high-temperature materials (98).
- Demonstrate (98) and transition (99) alternative paint/depaint technologies to reduce or eliminate volatile organic compounds (VOCs).
- Develop connector-plating system for improved electrical bonding (98).
- Transition corrosion and crack detection characterization technologies to advanced development for the inspection of aging airframe structures and identify capability to develop automated methods for aircraft inspection (99).
- Identify nonintrusive NDE technique to detect hidden corrosion (99).
- Conduct rapid, reliable, laser based ultrasonic inspection of composites and bonded structures (99).
- Identify and develop NDE/I techniques to provide process characterization information for control of aerospace processing operations (99).
- Identify degradation mechanisms and morphologies of aerospace coating systems (99).
- Develop corrosion kinetics with associated modeling and prediction capabilities (99).
- Identify nonhazardous metal cleaning and surface treatments to apply paints with extended life (99).
- Develop inspection techniques to ensure structural and electromagnetic integrity of LO structures (00).
- Transition MAUS (00).
- Characterize processes for decreasing cure time and increasing shelf life of repair materials (00).
- Demonstrate (00) and transition (04) ability to detect hidden flaws and multisite crack damage.
- Establish repair capability of bismalidimide (BMI) composite structures (01).
- Demonstrate new paint coating systems with increased life (01).
- Transition enhanced retirement for cause (01).
- Establish repair capability for AFR-700, a high-temperature polymer matrix composite (02).
- Demonstrate real-time vehicle health monitoring for launch vehicle propulsion subsystem (03).
- Develop NDE techniques for generic LO (04).
- Demonstrate ability to detect structural damage with built in test sensors (04).
- Demo enhanced CT for solid rocket motors (04).
- Demo insitu NDE for operational readiness (04).

GLOSSARY

AA – Avionics Directorate.
ACC – Air Combat Command.
ACPO – Advanced Composite Program Office.
AF – Air Force.
AFB – Air Force Base.
Affordability – A balance of risk, performance and cost.
AFMC – Air Force Materiel Command.
AFR700 – Air Force Resin 700 / An Air Force developed high-temperature composite.
AFSOC – Air Force Special Operations Command.
AFSPC – Air Force Space Command.
AGM – Air-to-Ground-Missile.
Air Force – U.S. Air Force.
AJ – Anti-Jam.
Al – Aluminum.
AL – Armstrong Laboratory.
ALC – Air Logistic Center.
Al-Li – Aluminum Lithium.
ALLTV – All Light Level TV
AMC – Air Mobility Command.
ANG – Air National Guard.
AQS – Under Secretary of Defense for Space Acquisition.
Army – United States Army.
ASC – Aeronautical Systems Center.
ASC/YFZ – F-22 SPO.
ASIP – Airframe Structural Integrity Program.
ATD – Advanced Technology Demonstrator.
AWACS – Airborne Warning and Control System.
BMI – Bismilimide.
C-C – Carbon-Carbon.
CDR – Critical Design Review.
CFC – Chloro Floro Carbon.
CFIPT – Customer Focus Integrated Product Team.
CM – Countermeasure.
cm^2 – squared centimeters.
CMC – Carbon Matrix Composite or Ceramic Matrix Composite.
CO_2 – Carbon Dioxide.
Cost – R&D, Acquisition and / or Operational & Support cost.
CPO – Corrosion Program Office
CRDA – Cooperative Research & Development Agreement.
CRMS – Composite Repair of Metal Structures.
CT – Computed Tomography.
CTIO – Coatings Technology Integration Office
CTC – Center Technology Council.
DARPA – Defense Advanced Research Projects Agency.
DAVID – Development of Advanced IR Detectors.
dB – Decibels.
DEA – Data Exchange Agreement.
DoD – Department of Defense.
E-O – Electro-Optical / Electro-Optics.
EO – Electro-Optical / Electro-Optics.
EO1 – Earth Orbiter 1.
ESD – Electro-Static Discharge.
EW – Electronic Warfare.
FDS – Flight Demonstrated System.
FI – Flight Dynamics Directorate.
FICOP – Fighter Configuration Plan.
FIV – (WL/FIV).
FLIR – Forward-Looking Infrared.
ft^2 – Squared Feet.
FY – Fiscal Year.
GaAs – Gallium Arsenide.
GHz – Gegahertz.
HazTox – Hazardous and Toxic.
HCF – High Cycle Fatigue.
HDBK – Handbook.
HFC 125 – A Halon replacement.
HgCdTe – Mercury Cadmium Telluride (or MCT).
HMD – Helmet Mounted Display.
hr – Hour.
HSC – Human System Center.
HSC/YA – HSC Human SPO.
HTSC - High-temperature Superconductor.
HUD – Heads Up Display.
HyTech – Hypersonic Technology.
ICBM – Intercontinental Ballistic Missile.
IEA – International Exchange Agreement.
IHPRPT – Integrated High Performance Rocket Propulsion Technology.
IHPTET – Integrated High Performance Turbine Engine Technology.
InP – Indium Phosphide.
IPT – Integrated Product Team.
IR – Infrared.
IRCM – Infrared Countermeasure.
IRST – Infrared Search & Track.
JDL – Joint Director of Laboratories.
JJ – Josephson Junction.
JSF – Joint Strike Fighter.
kgs – Kilograms.
KHz – Kilohertz.
ksi – Thousand Pounds Per Square Inch.
LANTIRN – Low Altitude Night Targeting IR Navigation.
lb – pound.
LBU – Laser-based Ultrasound.
LCC – Life Cycle Cost.
LEP – Laser Eye Protection.
Li – Lithium.
LLLTV – Low Level Light TV
LLUM – Long wavelength Low background Uniform MCT.
LO – Low Observable.
LPD – Low Probability of Detection.
LPI – Low Probability of Intercept.
LUIS – Laser Ultrasonic Inspection System.
LWIR – Long Wave Infrared.
M&P – Materials and Processes or Materials and Processing.
MAJCOM – Major Command.
MAP – Mission Area Plans.
MAUS – Mobile Automated Scanner.
MCM – Multi Chip Module.

GLOSSARY

MCT – Mercury Cadmium Telluride (or HgCdTe).

MEA – More Electric Aircraft.

MEMS – Microelectro Mechanical Systems.

ML – Materials Directorate.

MLI – ML's Integration and Operation Division.

MMC – Metal Matrix Composite.

MNS – Mission Needs Statement.

Mo – Molybdenum.

MRF – Multirole Fighter.

MSPLD – Magnatron Sputter Pulsed Laser Deposition.

MWIR – Mid-wave infrared.

NASP – National Aerospace Plane a former hypersonic transatmospheric aircraft demonstration program.

NDV – NASP Derived Vehicle, a NASP follow-on concept.

Navy – United States Navy.

NDE – Nondestructive Evaluation.

NDI/E – Nondestructive Inspection / Evaluation.

Ni – Nickel.

NIR – Near Infrared.

NLO – Nonlinear Optical or Nonlinear Optics.

nm – nanometer.

NVG – Night Vision Goggles.

OC-ALC – Oklahoma Air Logistic Center.

ODC – Ozone Depleting Chemicals.

OO-ALC – Ogden Air Logistic Center.

Ops – Operations.

ORD – Operational Requirements Document.

P&W – Pratt & Whitney.

PBr_3 – Phosphorus Tri-bromide.

PL – Phillips Laboratory.

PMC – Polymer Matrix Composites.

PO – Aeropropulsion and Power Directorate.

PW – Pratt & Whitney.

QPA – Qualitative Process Automation.

RF – Radio Frequency.

RL – Rome Laboratory.

RM&S – Reliability, Maintainability and Supportability.

RTM – Resin Transfer Molding.

S&T – Science and Technology.

SA-ALC – San Antonio Air Logistic Center.

SAF – Secretary of the Air Force.

SBIR – Small Business Innovation Research.

SBIRS – Space Based Infrared System.

SCC – Stress Corrosion Cracking.

SHPS – Survivable High Performance Sensor.

Si – Silicon.

SiC – Silicon Carbide.

SiO_2 – Silicon Oxide.

SM-ALC – Sacramento Air Logistic Center.

SMC – Space and Missile Systems Center.

SMLS – Subsystems SPO.

Sn – Tin.

SOF – Special Operational Forces.

Sol-Gel – Solid Gelatin.

SOTA – State-of-the-art.

SORD – System Operational Requirements Document.

SPO – System Program Office or Systems Project Office.

SSTO – Single Stage To Orbit.

STBBS – Science and Technology Bulletin Board System.

STTR – Small Business Technology Transfer.

SVELT – Spline Variational Elastic Laminate Technology.

T&E – Test and Engineering.

TAP – Technology Area Plan.

TAV – Transatmospheric Vehicle, a military spaceplane concept that is a follow-on to the NASP derived vehicle (NDV).

TBCCO – Thallium Barium Copper Calcium Oxide.

TCC – Thermal Control Coating.

Ti – Titanium.

TiAl – Titanium Aluminide.

TMP – Technology Master Planning.

TPAM – Technology Panel for Advanced Materials.

TPIPT – Technology Planning Integrated Product teams.

TPM – Thermal Protection Materials.

TR – Technical Report.

Trimarc – A trade name for a gamma TiAl otherwise described as Ti-6242, or Ti-6Al-2Sn-4Zr-2Mo.

TTIPT – Technology Thrust Integrated Product Team.

TTW – Thrust-to-Weight Ratio.

UAV – Uninhabited Aerial Vehicle.

UCAV – Uninhabited Combat Aerial Vehicle.

UK – United Kingdom.

US – United States.

USAF – United States Air Force.

USAFA – USAF Academy

USD/DDRE – Undersecretary of Defense, Deputy Director of Research and Engineering.

USSOCOM – US Special Operations Command.

UV – Ultraviolet.

Vis – Visible.

VOC – Volatile Organic Compounds.

WL – Wright Laboratory.

YBCO – Yttrium Barium Copper Oxide.

ZGP or $ZnGeP_2$ – Zinc Germanium Phosphide.

ZnS – Zinc Sulfide.

ZnSe – Zinc Selenide.

Zr – Zirconium.

INDEX